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Determination of the Spatial Relationship of Available Phosphorus for Seven Sites in South Dakota

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DETERMINATION OF THE SPATIAL RELATIONSHIP OF AVAILABLE PHOSPHORUS FOR SEVEN SITES IN SOUTH DAKOTA

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DETERMINATION OF THE SPATIAL RELATIONSHIP OF AVAILABLE PHOSPHORUS FOR SEVEN SITES IN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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For in much wisdom is much vexation, and he who increases knowledge increases sorrow. - Ecclesiastes 1:18 Half of what we know is wrong, the problem is we don't know which half.

This thesis is dedicated to my younger brother Craig.

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INTRODUCTION

One of the first great advances in agriculture came with the observation that crop production could be increased with the additions of animal manures, plant residues, and soil amendments (Tisdale and Nelson, 1975). The study of soil fertility since then has tremendously refined those observations. Due to the advancement of soil testing, kinds and amounts of nutrients needed for a specific crop are being determined. Most fertilizer recommendations are now based on soil testing techniques performed on soil samples brought in from the field. The question now becomes: do those samples truly represent the fertility status of the field? Can the level of fertility for a 40 hectare field be determined from 2 or 3 half-kilogram soil samples? If those samples are not a good representation of the field, then fertilizer recommendations based on those samples may actually be a disservice to the farmer (James and Dow, 1972).

Soil sampling has been studied by many investigators for many years and this is one more endeavor in that area. The main objective of this study was to determine efficient sampling distances for estimating soil phosphorus levels of given fields. The semivariogram was used in this study to determine sampling distance.

REVIEW OF LITERATURE

This review will be in two sections. The first deals with the different sources of variation found in soil fertility testing (Part I) while the second pertains to the semivariogram application for describing the variability of soil properties (Part II).

SOURCES OF VARIATION IN SOIL FERTILITY TESTING

The three principal sources of variation in soil testing are:

A. Soil collection and laboratory analysis
B. Seasonal
C. Spatial or field (Cameron et al., 1971; Cline, 1944)

A. Soil Collection and Laboratory Analysis

Tools are used in the first step of sample collection, and can contribute to soil testing variability. A sampling tool should provide a sample that is:

1) uncontaminated
2) approximately uniform in cross section to the desired depth
3) reproducible (Cline, 1944)

Dissimilar cores in successive samplings may bias the estimate of the mean for a composite sample by unequal weighting of different parts of an area (Cline, 1944). The three principal types of sampling tools are:

1) blades - spades, shovels, knives, etc.

2) tubes - open sided and plain cylinder, constricted-tip and uniform bore
3) augers - wood-bit, post-hole, and sheathed (Cline, 1944)

Welch and Fitts (1956) using an auger, tube, trowel, and spade to collect soil samples for analysis of pH, P, K, and organic matter (O.M.), found no significant differences among the tube, trowel, and spade for any of the analyses. The auger samples were statistically different from the other three sampling tools in pH and O.M. analyses but the differences were small enough to conclude that any of the tools could be used with good results on the soils sampled. The important factor was to obtain a uniform core or slice of soil to the desired depth at each spot in the field.

Depth of sampling can also affect the variabiltiy of samples (Beckett and Webster, 1971). Soil properties vary with depth due to different management and seasonal changes (Beckett and Webster, 1971; Raupach, 1951; Towner, 1968). Vertical distributions vary from one sampling location to another, and therefore individual depths are more variable than an overall combination of all depths (Cameron et al., 1971). Differences in sampling depth, due to careless control by a single worker, or the dissimilar procedures of different workers are sources of inconsistency (Beckett and Webster, 1971; Opio, 1971).

After the samples are collected, the handling of the samples can affect the soil test results. Soil samples are usually dried and pulverized for convenience of handling (Eik et al., 1975). Bartlett and James (1980) pointed out that the soil is changed by drying and storing it, and that this is often ignored in soils research. Unfortunately, no convenient, simple, or suitable alternative to drying soil samples exists (Bartlett and James, 1980). Drying soil samples is still the preferred procedure as long as the problems involved are understood (Bartlett and James, 1980). Changes in mineralizable N, S, K, Mn, soil pH, and increased solubility and oxidizability of soil organic matter were the main problems involved in drying soil samples (Bartlett and James, 1980; Eik et al., 1975). Method of sample storage (moist vs. dry) can change the soil test results (Eik et al., 1975; McIntyre, 1967). Of the principal nutrients, phosphorus seems the least vulnerable to change, potassium intermediate, (exchangeable potassium differs widely among soils at varying moisture contents (Grava et al., 1961; Luebs et al., 1956)) and mineralized nitrogen the most susceptible to change (McIntyre, 1967).

Nitrate-nitrogen content can change significantly if the soil sample is kept in a field moist condition. Improper handling of soil samples between the time of collection and the analysis in the laboratory can result in an erroneous nitrate-nitrogen analysis. In one experiment, the nitrate-nitrogen concentration increased by 7.6 ppm when field moist samples were subjected to a 30^{0} C temperature for a 24 hour period, and after 48 hours the concentration had increased by 14.2 ppm (Westfall et al., 1978).

Careful manipulation of soil samples after collection reduces laboratory error, adding little to the over all variability in soil testing. The variance due to laboratory error is negligible when the samples are handled carefully and analyses done properly (Post, 1924). The limit of accuracy is determined by the sample, and the errors incurred in sampling soils in the field are greater than the analytical errors in the laboratory (Cline, 1944; Hemingway, 1955; Horton and Stinson, 1939). An accurate soil analysis cannot reveal the true nature and condition of an area unless the sample is representative of the soil in that area (Hemingway, 1955; Horton and Stinson, 1939).

Accuracy in the analysis of soil properties of a field is most often limited by field variation not lab techniques. Often greater precision in the lab is being used than is necessary, and refinement of lab methods would be inefficient (Cline, 1944; Reed and Rigney, 1947).

In another study, it was determined that a realistic estimate of laboratory variance is much greater than the estimate commonly obtained from duplicate analyses conducted at one time in one lab. This greater lab variance was attributed to long term variation within a lab, possibly caused by changes in reagents, climatic conditions, and technical staff. Understanding this component of variation was considered essential when the precision of a soil test value is estimated (Mountier, et. al., 1966). The most straightforward procedure for reducing variance is to repeat the analysis for each sample, but this is seldom considered practical (Moutier and During, 1967). In the study by Mountier and During (1967), repeat testing of the samples eight weeks later lowered the within-batch variance, but only in the cases of calcium and phosphorus was it considered worthwhile. Even in these the gain was not considered to be outstanding.

B. Seasonal Variation

Chemical properties of soils also vary with time (Cline, 1944; Collins et all., 1970; Raupach, 1951). Some do not regard this as a serious factor in soil testing (McIntyre, 1967). The ideal sampling time is just before planting. If samples are taken some time ahead of this desirable sampling date, following changes in the field can mean the soil samples no longer represent the field (McIntyre, 1967). A number of opposing factors, such as microclimate, salt content, and microbiological processes, exert their influence to varying degrees upon the soil (Raupach, 1951). Significant seasonal changes in organic phosphorus in a north-facing slope of a Boroll soil were found in South Dakota (Westin, 1978). The pH of the plow layers of thirteen soil series at 19 sites in southern Michigan varied as much as 1.6 units from May through September (Collins et al., 1970). Cameron et al. (1971) and Ball and Williams (1968), concluded that any seasonal variation within the main growing season must be very small and is often masked by random field variation. A precise estimate of minor seasonal changes would require more extensive sampling.

C. Field or Spatial Variation

The largest source of variation in soil testing is the spatial variation found within the field being tested (Cameron et al., 1971). The source of this variation can be attributed to two main factors:

1. The variation originating from the formation and development of soils.

2. The variation imposed by man's treatment of the soil. (Beckett and Webster, 1971; James and Dow, 1972)

1. Soil is a naturally occurring body undergoing continual change. The qualities of a soil are the combined effects of climate and biological activity acting upon parent material, as modified by topography over periods of time (Jenny, 1941).

Parent material may vary irregularly over short distances as in deposits of a braided stream or more gradually across the outcrop of a sedimentary rock (Beckett and Webster, 1971). Soils formed from transported materials tend to be more variable than those weathered from bedrock in place (Beckett and Webster, 1971). Ulrich (1949) in Iowa found physical profile properties of loess derived soils changing with increasing distances from the loess source. Clay content of loess soils increased, whereas aeration, permeability, and total porosity decreased with increasing distance from the Missouri River bottomlands. Within an area, soil losses by wind and water erosion and the associated deposition produce short range alterations of soil parent material and give rise to recurrent patterns of dissimilar soils (Beckett and Webster, 1971).

Topography influences soil formation and produces regional differences in soil properties (Beckett and Webster, 1971). Short range changes in micro-relief and drainage can cause repeated changes in soil properties causing variations in saturation or aeration. (Beckett and Webster, 1971). In North Dakota, differences in plant responses to landscape position were shown to exist primarily due to changes in soils and their associated properties (Malo and Worcester, 1975). Results similar to those in North Dakota were also found in southeastern Saskatchewan. The pedological and micro-climatological differences due to different topographical positions affected the yields of wheat more than soil fertility and fertilizers (Spatt and McIver, 1972).

Climate affects soil variability. Climate directly effects soil formation by rainfall and temperature. As a general rule, the greater the amounts of precipitation and the warmer the climate, the more intense the weathering, leaching, and erosion will be. Climate indirectly influences soil formation by its control over the type and amount of vegatation that can grow in a region.

Biological activities increase local variability. Differences among some soils have resulted primarily from differences in vegetation. Plants are considered to be both a dependent and independent variable in soil formation (Jenny, 1958). Plants directly affect the soil properties of organic carbon, total nitrogen, pH, and bulk density (Crocker, 1960). The localized uptake of nutrients and water by plants add to the variability. The local effects of burrowing or wallowing animals, mound building by ants, and worm casts, all produce heterogeneity faster than it can be homogenized by diffusion and mixing (Beckett and Webster, 1971; Donahue et al., 1983).

Finally, time is also a factor affecting soil variability. The age of a soil does seem to influence its variability. Harradine (1949) found that recent soils varied in their properties to a larger extent than did more mature soils. A good correlation between decreasing variability with increasing maturity was obtained from the measurements of apparent density, colloidal clay content, pH, and total nitrogen.

2. The factors previously discussed are all natural sources of variability. Additional variability results from human management of the soil. Man's influence on soil variability can be categorized into three main areas:

1) Fertilizer and lime application
2) Tillage and cropping practices
3) Livestock grazing(Beckett and Webster, 1971)

1) Fertilizer Application

As a general rule, the inherent soil fertility of virgin soils is less heterogeneous than the soil fertility of land where lime, manure, and fertilizers have been applied (Leo, 1963). In other studies there was little difference between wasteland and cultivated soils which had not received phosphorus, potassium, or lime. However soils which had received lime and fertilizers within three years of the sampling date showed appreciably greater sampling errors than those which had not (Gallagher and Herlihy, 1963; Hemingway, 1955).

The placement or imperfect broadcasting of fertilizer compounds the soil variability (Beckett and Webster, 1971). High rates of fertilizer placed in or near the row make it difficult to obtain a sample of soil which contains the average amount of nutrients which represents an entire area. If a sample is taken at or near a row, the results may be misleading in that they may indicate a higher level of nutrients than actually exists throughout the soil as a whole (Horton and Stinson, 1939; MacLean and Summerby, 1945). The differences continue for a long period following ferilization and are apparent to some degree even after thorough cross cultivation (Horton and Stinson, 1939). Systematic sampling could be efficient if the sampling pattern did not run parallel to the artificial high and low strips caused by banded fertilizers (McIntyre, 1967).

2) Tillage and Cropping Practices

Ike and Clutter (1968) state that cultivation would tend to decrease variation within a field, especially organic matter content and its dependent variables. On the other hand, Beckett and Webster (1971) say row cultivation and growth of row crops will add more heterogeneity to soil chemical properties. In another study (Hulburt and Menzel, 1953) a moldboard plow, disk harrow, spring-tooth harrow, and rotary tiller were used to mix a radioactive phosphorus fertilizer, applied by different methods, into the soil. All shallow tillage operations mixed the phosphorus to a depth of less than 2.5 cm. Deep tillage operations varied enormously in their abiliity to uniformly mix the phosphorus with the surface 15 cm of soil. Two rotary till operations were necessary to mix the soil uniformly to 15 cm. The spring-tooth harrow and disk harrow did not mix the phosphorus with the lower part of the tilled section. The disk harrow also left a nonuniform horizontal distribution of phosphorus. The moldboard plow placed most of the phosphorus in the lower part of the tilled section (Hulburt and Menzel, 1953).

3) Livestock grazing

Grazing produces manure patches rich in phosphorus and urine patches rich in potassium. In some cases grazed land showed similar variation to land which had received fertilizers (Beckett and Webster, 1971; Ferrari and Vermeulen, 1955; Hemingway, 1955)

With all the sources of variation superimposed on each other it is not surprising that conflicting results and conclusions concerning soil testing exist. Most soil variation within a field can be attributed to variability over relatively small distances (Beckett and Webster, 1971; Cameron et al., 1971). Up to half of the variance in soil properties within a region or field may already be present within areas as small as one to ten square meters (Beckett and Webster, 1971; Young, 1973). Even on relatively uniform, non-cultivated and freely drained soils a large degree of the spatial variability for pH, exchangeable cations, extractable phosphate, and soil moisture occurs over distances of a centimeter and meter (Ball and Williams, 1968). One way to handle this variability is with composite sampling. Composite sampling is considered to be effective only after soil variability has been determined (Post, 1924). Once soil variability has been determined, it is possible to calculate the number of samples needed to be within the limits of a certain error (Cline, 1944; Post, 1924). The general assumption has been that soil variation gradually changes across large fields or even within the so called uniform strata of the field (Hammond et al., 1958). This assumption is not always true (Hammond et al., 1958). The variability is not always uniformly dispersed over a field (Cameron et al., 1971). In a study by Cameron et al. (1971), one 2-ha area required only one core to estimate soil P while the most variable 2-ha area required over 100 cores for the same accuracy and precision. These extreme ranges of variation may exist from area to area within a field (Cameron et al., 1971). Intensive sampling to produce a reliable mean may not always reflect the true status of the field if the variability from position to position is considerable (Hemingway, 1955).

Variability may or may not increase as a sampling area is increased (Beckett and Webster, 1971; Hemingway, 1955). In one study, areas of 12.15, 2.02, 0.40, and 0.004 hectares were randomly selected from each of four fields with each field having a uniform soil type. Six samples were taken at more or less equal distances along each of four lines running across the sampling areas at a slight angle to the cultivations. It was determined that distance between sampling sites had no influence on increasing or decreasing sampling error or that sampling error increased as the sampled area increased in size (Hemingway, 1955). Ferrari and Vermeulen (1955) concluded that on the average, the size of the field had no effect on the magnitude of the sampling error. This was considered applicable only on areas between 0.3 and 2.5 hectares. In another study (Cameron et al., 1971), the general results showed a very gradual increase in the number of samples required with increasing field size, but this increase was not proportional to field size. The number of samples required, which ranged from 21 cores in a field of 0.4 ha to 28 cores in a field of 32 ha, increased most rapidly for P. In some cases, the number of cores for areas greater than 4 ha leveled off and remained fairly constant (Cameron et al., 1971).

Up to this point, soil variation and the sources of that variation have been discussed. It serves as an important reminder of the problems faced by the people involved with soil testing and with correlating those soil tests to fertilizer recommendations. With the many sources of variation in the soil, it is easy to understand why conflicting reports dealing with soil sampling exist. Soil sampling is not the only source of error in the fertilizer recommendation process. Imprecise correlation between the soil chemical analysis and plant growth along with errors of calibration also add to that error. (McIntyre, 1967). The high cost of increasing sampling precision is not justified if there is low precision in the other areas of the fertilizer recommendation process (McIntyre, 1967).

THE SEMIVARIOGRAM

The field of geostatisitcs has been developed and applied mainly in the area of mining. It is the study of the spatial distribution of useful mining values for engineers and geologists (Matheron, 1963). Ore-deposit evaluation through determining grade, thickness, and accumulation of the ore is an important application (Matheron, 1963). Recently some of the geostatistical theories have been applied in the field of agronomy and soil science. Vieira (1982) calculated semivariograms for surface temperature, yield of wheat, and soil carbon percentage. Burgess and Webster (1980a) applied semivariograms and punctual Kriging to produce maps of sodium content, stoniness, and thickness of cover loam based on data from detailed soil surveys.

The fundamental geostatistical theory used to describe spatial variability is called the "Theory of Regionalized Variables" (Matheron, 1963). In short, a variable is considered to be a "regionalized variable" if it varies from one place to another with an obvious continuity, but the variable cannot be represented by an ordinary, utilizable function (Davis, 1973). It should be pointed out that classical probability statistical concepts are insufficient to handle these regionalized variables because they do not take into account the spatial aspect of the variables, which is a very important feature (Matheron, 1963). Independency or random spatial distribution of field data has to be assumed before the classical statistical methods such as analysis of variance or coefficients of variation can be measured (Vieira, 1982). The assumption of random spatial distribution cannot be made until it is shown that no correlation between samples with distance exits. The geostatistical tool to measure the correlation, and differentiate between dependent and independent variables is called the semivariogram (Vieira, 1982).

Suppose a series of samples have been collected at regular intervals along a transect to obtain values of a regionalized variable Y(i), i = 1,2,3,...n. It can be surmised that the value of Y at a given point is related or correlated in some manner to the value of other points some distance away. An intuitive expectation would be that points closer together would have a stronger correlation or relationship than points separated by longer distances (Davis, 1973). The shortest distance between samples and integer multiples of that distance are represented by a number referred to as a lag. For example, if 50 meters is the shortest interval distance along a regular transect, then 50 meters would represent a lag of 1, 100 meters would equal a lag of 2, etc. The letter h will be the variable representing the lag number; h can be equal to 1,2,3...m-1, where m = the number of points in the transect. The relation between pairs of points h intervals apart can be expressed as one-half the variance of the differences between all such pairs. It is called semivariance and is represented by the computational form of:

$$\gamma(h) = 1/2n \Sigma (Y[i] - Y[i+h])^2$$

where:

h = lag
$\gamma(h)$ = semivariance
n = number of pairs of points which are separated by the distance represented by h (Vieira, 1982; Davis, 1973)

The semivariance is a measure of the similarity between points a given distance, h, apart (Burgess and Webster, 1980a). The more alike the points are, the smaller $\gamma(h)$ will be; and the more dissimilar they are, the larger $\gamma(h)$ will be (Burgess and Webster, 1980a). For short distances of h, small values for $\gamma(h)$ would be expected and as h becomes longer, $\gamma(h)$ should become larger because of a progressively greater independence between points (Vieira, 1982). The relationship between the semivariance and the distance between points can be represented by a graph of $\gamma(h)$ plotted against h. This graph is called a semivariogram and is used to define the distance over which values are interdependent. Figure 1 is an example of a semivariogram (Burgess and Webster, 1980a; David, 1977; Davis, 1973).

As can be seen, the shorter h is, the smaller $\gamma(h)$ is; but as h increases so does $\gamma(h)$ until after a certain distance of h, $\gamma(h)$ remains constant. Three terms are used to describe this relationship:

1) sill
2) range
3) nugget variance

The value of $\gamma(h)$ at the point where it reaches its maximum value and then remains constant is known as the sill. The sill is represented by the term C + Co. The corresponding distance represented by the letter A is referred to as the range. The range represents the distance at which the values of Y are considered to be spatially dependent. Samples separated by a distance more than the range are considered to be independent (Burgess and Webster, 1980a; Davis, 1973). The last term is the nugget variance, or chaotic component, as it is sometimes called by statisticians (David, 1977). By definition $\gamma(h) = 0$ when h = 0, but as seen on Fig. 1, the curve does not pass through

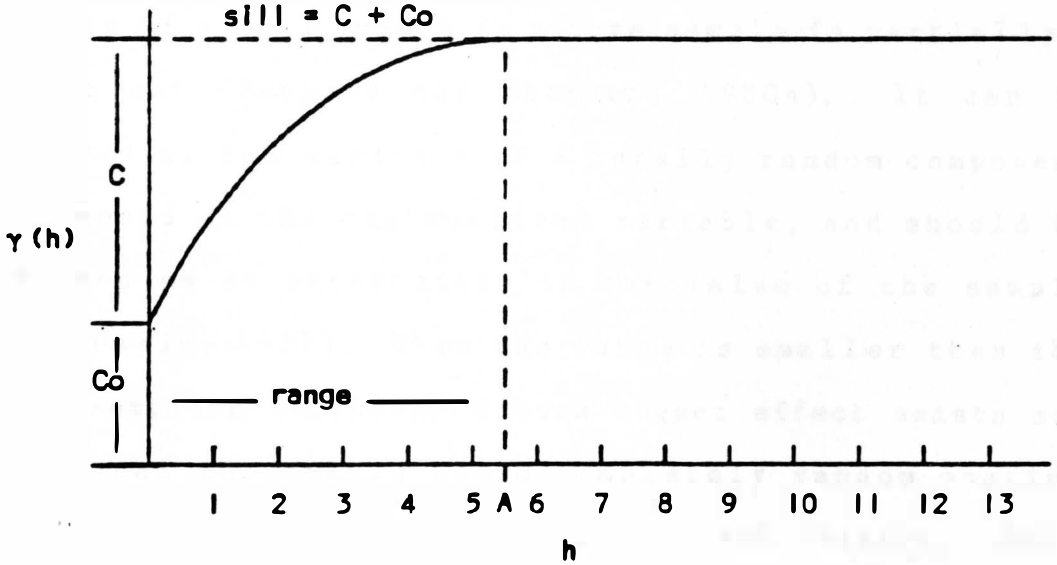


Figure 1. Semivariogram. Range, A, is the distance at which $\gamma(h)$ = sill.

positive finite value to which $\gamma(h)$ approaches as h approaches 0. This intercept is known as the nugget variance, (represented by Co) and the phenomenon in general is called the nugget effect (Burgess and Webster, 1980a). The terms were derived from gold mining in which the inclusion of a gold nugget in a core sample is partially a chance event (Burgess and Webster, 1980a). It can be considered as the variance of a totally random component superimposed on the regionalized variable, and should be considered as an uncertainty on the value of the sample itself (David, 1977). When the range is smaller than the closest sampling distance, a pure nugget effect exists and the physical phenomenon has a completely random spatial distribution at the sampling interval used (Vieira, 1982). Plotting another semivariogram with samples taken at smaller intervals may reveal an adequate structure. If not, a pure nugget effect exists allowing classical statistical methods to be applied (David, 1977; Vieira, 1982).

Typically when $\gamma(h)$ is computed at various values of h, the calculated points will scatter around a theoretical line. It then becomes essential to fit a smooth curve to these points to obtain an estimate of the semivariogram. There is no general mathematical formula to depict the shape of soil semivariograms. The selection of the correct semivariogram curve can be very difficult in practice (Burgess and Webster, 1980a; Davis, 1973).

Automatic curve fitting is not recommended in mining geostatistics. However Viera (1982) states if the theoretical model is a conditional positive definite function, no restriction should be imposed in determining how the model is obtained. These are the basic steps of creating a semivariogram.

In the previous discussion, all that has been considered has been a transect which is one dimensional. In mining, usually a three dimensional system is considered. For our purposes of semivariogram application, samples are usually collected on a regularly spaced two dimensional grid.

A series of samples have been collected at points on a regular grid as shown in Figure 2. The vector h now has directional properties as well as distance properties; and it is also reasonable to expect that the degree of influence might be different in different directions (Davis, 1973). Four semivariograms can easily be calculated from a regular grid:

1) east-west semivariogram
2) north-south semivariogram
3) northeast-southwest semivariogram
4) northwest-southeast semivariogram

Ordinarily, at least three semivariograms are constructed, two at right angles to one another, and one more at a 45 degree angle (Davis, 1973). The three are then distribution of values is said to be isotropic (Davis,

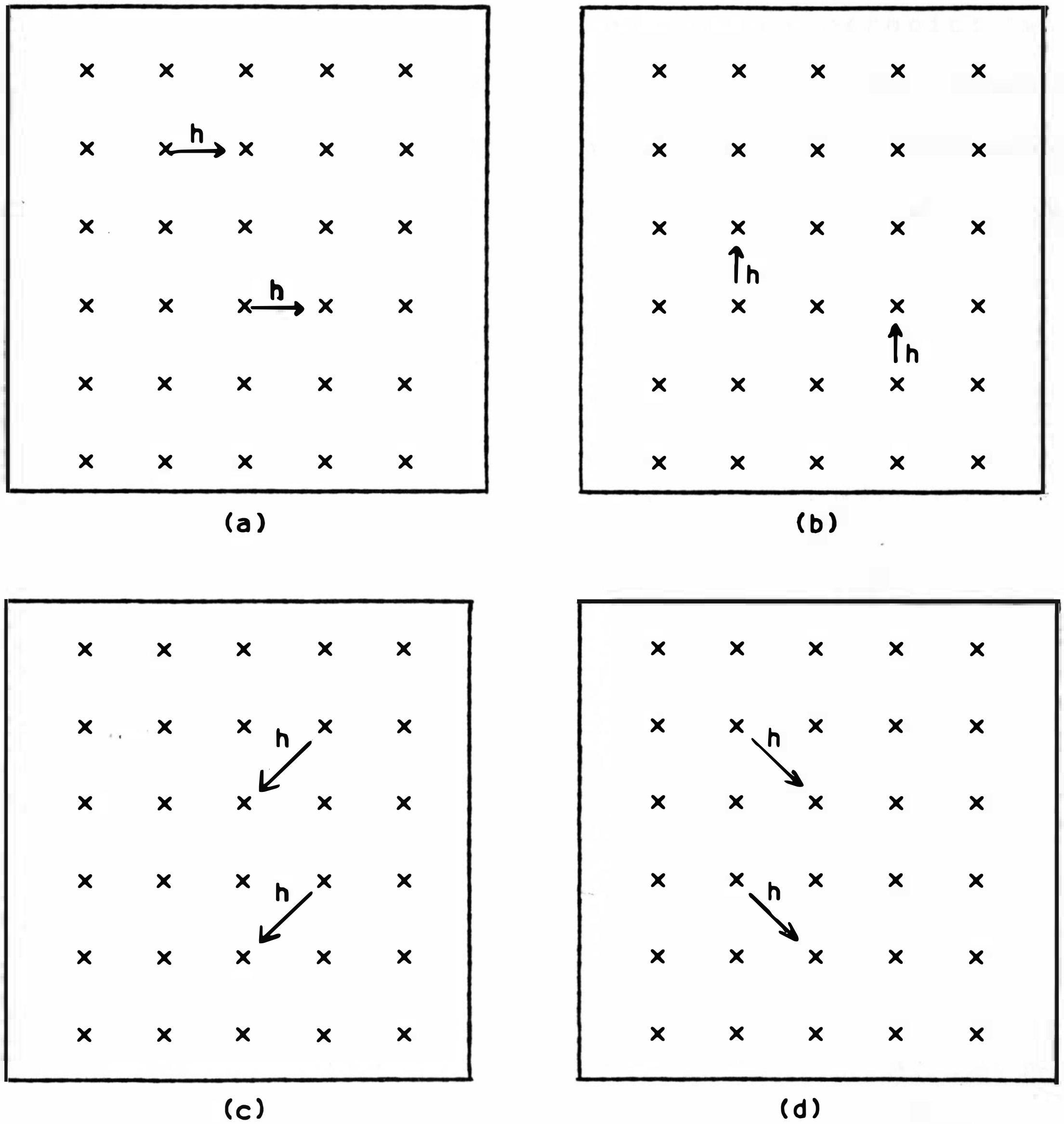


Figure 2. Semivariance is calculated for all pairs of points h distance apart. (a) east-west vector (b) north-south vector (c) northeast-southwest vector (d) northwest-southeast vector.

1973). When the semivariograms are different for different directions, they are classified as anisotropic; which creates the problem of how to transform them into isotropic semivariograms (Vieira, 1982). Transformation of anisotropic semivariograms will not be considered here. A semivariogram based on only one direction is valid only for changes in that direction (Davis, 1973). Therefore, in this paper the semivariogram curve will be fitted to a combination of at least three directional semivariograms.

MATERIALS AND METHODS

Seven sites were selected in eastern South Dakota (Appendix Figure A). Four sites were located in Kingsbury County, two in Brown County, and one in Brookings County. The Brookings County site was 5.6 hectares in size and the other six sites were 4.6 hectares.

Kingsbury County (Sites 1 - 4)

Site one was a gently undulating landscape with Buse, Parnell, Poinsett, and Waubay soils. Buse soils are fine loamy, mixed, Udorthentic Haploborolls. Parnell soils are fine, montmorillonic, frigid Typic Argiaquolls. Poinsett soils are fine silty, mixed, Udic Haploborolls. Waubay soils are fine silty, mixed, Pachic Udic Haploborolls. It had been on a corn-barley rotation with corn during 1982 when soil samples were collected. Thirty seven kg per hectare of ammonia polyphosphate (10-34-0) was broadcast in 1982. From 1975 to 1981 53 to 64 kg per hectare of 10-34-0 was banded at planting time. Tillage during this time consisted of chisel plowing and disking.

Site two was a gently undulating landscape with Buse and Poinsett soils. The cropping sequence had been continous corn with the same fertilizer application and tillage operations as site one.

Site three was a gently undulating landscape with

Buse, Poinsett, and Waubay soils. It had been in a corn-small grain rotation for four years with corn in 1982 when the soil samples were collected. One hundred twenty five kilograms per hectare of diammonium phosphate (18-46-0) was applied in bands each year during those four years. The main tillage operation consisted of a moldboard plowing in the fall each year.

Site four was a gently undulating landscape with Buse, Parnell, Poinsett, and Waubay soils. It had been an oats-corn-soybean rotation with soybeans in 1982. The main method of fertilizer application was broadcast, and the main tillage operation was disking.

Brown County (Sites 5 - 6)

Site five was a nearly level landscape, 0-2% slope. It had been in continuous wheat for three years and had 12 kg of phosphorus applied per hectare in bands. It was a reduced tillage operation with planting by a pony press drill.

Site six was a nearly level landscape, 0-2% slope. It was in wheat in 1981 and barley in 1982. Similar fertilizer applications and tillage operations used in site five were used in site six.

Brookings County (Site 7)

Site seven was a nearly level landscape, 0-2% slope, with a Fordville soil, a member of the fine loamy over sandy or sandy-skeletal, mixed, Pachic Udic Haploborolls. It had been in alfalfa for several years, and no fertilizers had been applied during that time.

Sampling Procedures

Samples were systematically collected from square grids measured in the field. Samples from 15 by 15 grids with 15.3 meters between samples in the north-south and east-west directions were collected for sites 1 through 6, site 7 was a 14 by 14 grid with 18.2 meters between samples along north-south and east-west lines. Single point samples were collected at the grid points with hand probes (2.5 cm diameter) to a depth of 15 cm in sites 1 through 6. Samples in sites 1 through 3 were collected equidistantly between corn rows and at site 4 equidistantly between soybean rows. Samples from sites 5 and 6 were collected on small grain stubble fields. Site 7 samples were collected on a recently mowed alfalfa field with a hydraulic probe (7.6cm diameter) to a depth of 60 cm, but only the top 15 cm were used in this study. Sites 1 through 4 were collected in July of 1982 with no site taking more than three days to collect. Sites 5 and 6 were taken in August 1982 within a three day span. Site 7 samples were taken in June 1981 within two days.

Chemical Analysis

The samples were analyzed for available phosphorus in the South Dakota State University soil and plant analysis laboratory. The analysis is an adaption of the Bray and Kurtz number 1 method. The procedure is outlined in Plant Science Pamphlet # 55, South Dakota State University Agricultural Experiment Station July 1980, pages 5-7.

An outlier procedure was used in which soil test values, and for this study, phosphorus values which were very high were transformed into what were considered to be more representative values. For example, suppose most of the soil phosphorus values within an area were in the 10 to 20 mg/kg range, but one value within that area exceded 90 mg/kg. That value may actually exist in the field, but it is considered to be an outlier that did not really represent that area. The guidelines for detecting and transforming outliers were:

1. The average and standard deviation of soil phosphorus values for each site were calculated. The standard deviation was doubled and added to the average, (referred to as the first cutoff point). Any soil test value equal to or greater than the first cutoff point was considered to be a possible outlier.

2. Three or more test values equal to or greater than the first cutoff point contiguous to one another were

considered representative of the area and not transformed.

3. The remaining values equal to or above the cutoff point were tested again. For single points, the average and standard deviation of the surrounding eight values were calculated; the standard deviation was multiplied by four and added to the average (referred to as the second cutoff point). The possible outlier was compared to the second cutoff point. If it was larger than the second cutoff point it was considered an outlier and was transformed. The transformation simply consisted of replacing the outlier with the average of the surrounding eight points.

If two possible outlier points were contiguous, they were each handled similarly to single points. Each point was tested separately with the seven closest points (excluding the possible outlier point adjacent to it) being used to calculate the second cutoff point for testing the possible outliers as outlined above.

4. Single points or two points next to each other on the borders that were above the first cutoff point were automatically replaced by the average of the nearest five or four (or three or two points if it was in the corner) without calculating the second cutoff point.

The rationale used for transforming outliers was that they were not representative of the area and if allowed to remain, would cause inflated semivariogram values which would lead to an unrepresentative semivariogram.

The evaluation began with an inspection for and transformation of outliers. Next, the semivariograms for the north-south, east-weat, northwest-southeast, and northeast-southwest directions were calculated as outlined in the literature review and graphed.

Selection of a model to fit the semivariograms began with a visual inspection of the four directional semivariograms to see if a discernable pattern emerges. If three directional semivariograms follow approximately the same pattern, the area was considered isotropic (Davis, 1973). If the semivariograms were not the same for different directions, they were considered to be anisotropic. It must be kept in mind that if an area is anisotropic, the distribution of values will be different depending on which direction is taken when samples are collected (Davis, 1973).

If the area was isotropic, the next step was to select a model to fit the semivariograms. As stated before, there are no standard models or procedures for deriving what is considered to be the best fitting model to describe the shape of soil semivariograms. In this paper, the two models used will be the linear and quadratic models. Linear and quadratic models were fitted to the three directional semivariograms over varying lags. The object was to derive the best fitting model over the longest range for describing the spatial relationship between soil samples. Comparison of linear and quadratic models over different lags may result in more than one equally good combination (Burgess and Webster, 1980b).

The range for a linear model was equal to the distance represented by the highest h value used. The range for a quadratic model was determined by taking the first derivative of the model and setting it equal to zero, and then solving for h. At this distance, $\gamma(h)$ was at its maximum value (the sill value) and the corresponding distance represented by h was the range. The range cannot go beyond the largest h value used in modeling. If the first derivative gives an h value larger than the h value used in the quadratic model, it was disregarded, and the range was represented by the largest h value used in the model. The sill was the $\gamma(h)$ value corresponding to the range value h, and the nugget effect was equal to the $\gamma(h)$ intercept.

RESULTS AND DISCUSSION

Site 1

The original soil test values for phosphorus at site 1 are shown in Figure 3. The average value was 17.5 mg/kg and the standard deviation was 13.3. The outlier values are circled in Figure 3 as are the transformed values shown in Figure 4. A graph of the directional semivarograms for the transformed data is shown in Figure 5. A visual inspection of the semivariance graphs of site 1 indicates a similarity between the north-south, east-west, and northeast-southwest semivariograms. The three semivariograms follow the same trend until the sixth lag which equates to a distance of 91.4 meters.

Linear and quadratic models were fitted to the semivariogram values of the one through six lags for the north-south and east-west directions plus the values for the 1.4 through 5.6 lags on the northeast-southwest direction. Table 1 has the parameters of the semivariogram models for site 1. Figure 6 represents the best linear model, and Figure 7 represents the best quadratic model. The data indicates that there was a strong spatial relationship between samples separated by a distance less than 91.4 meters as denoted by the linear model and 79.2 meters as denoted by the quadratic model. Samples taken within 91.4 meters are not considered to be independent of one another.

SITE 1
mg Phosphorus/kg Soil
Original Values

6	10	20	14	7	9	17	12	10	16	13	21	12	13	39
9	27	16	8	18	14	66	16	10	10	9	24	18	11	12
10	14	34	9	9	14	18	11	27	10	20	18	19	18	31
9	8	8	25	11	16	11	10	18	12	100	35	20	7	15
8	9	9	12	8	44	19	11	7	10	24	16	17	7	8
7	9	5	11	10	23	18	8	20	14	11	16	34	22	10
13	10	11	7	13	38	36	27	10	12	24	57	11	12	9
6	7	16	16	16	55	60	52	12	11	12	11	13	14	39
11	10	16	10	18	39	52	45	6	11	22	26	16	7	10
25	15	18	11	14	26	32	43	22	35	9	12	27	22	6
18	10	8	23	15	27	30	29	16	13	11	10	24	6	8
9	13	10	11	13	19	15	13	5	7	8	13	14	4	5
10	20	8	8	9	24	11	7	7	15	7	22	11	5	12
14	11	10	6	8	18	12	28	9	11	82	18	33	18	10
7	18	11	9	8	26	24	17	16	64	21	19	21	26	48

Figure 3. Original soil phosphorus test values for site 1.

SITE 1
mg Phosphorus/kg Soil
Transformed Values

6	10	20	14	7	9	17	12	10	16	13	21	12	13	39
9	27	16	8	18	14	14	16	10	10	9	24	18	11	12
10	14	34	9	9	14	18	11	27	10	20	18	19	18	31
9	8	8	25	11	16	11	10	18	12	18	35	20	7	15
8	9	9	12	8	15	19	11	7	10	24	16	17	7	8
7	9	5	11	10	23	18	8	20	14	11	16	34	22	10
13	10	11	7	13	38	36	27	10	12	24	16	11	12	9
6	7	16	16	16	55	60	52	12	11	12	11	13	14	39
11	10	16	10	18	39	52	45	6	11	22	26	16	7	10
25	15	18	11	14	26	32	43	22	35	9	12	27	22	6
18	10	8	23	15	27	30	29	16	13	11	10	24	6	8
9	13	10	11	13	19	15	13	5	7	8	13	14	4	5
10	20	8	8	9	24	11	7	7	15	7	22	11	5	12
14	11	10	6	8	18	12	28	9	11	16	18	33	18	10
7	18	11	9	8	26	24	17	16	15	21	19	21	26	18

Figure 4. Transformed soil phosphorus test values for site 1.

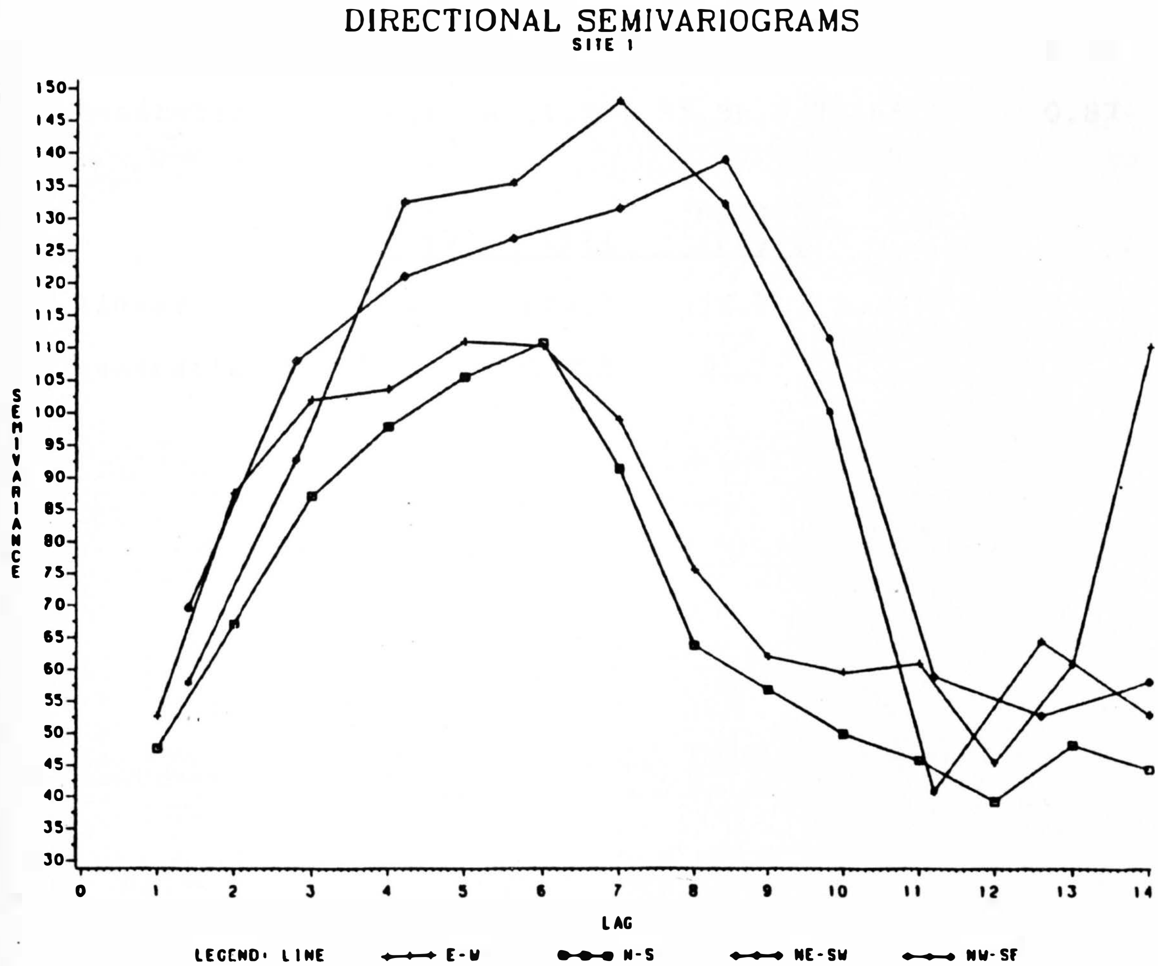
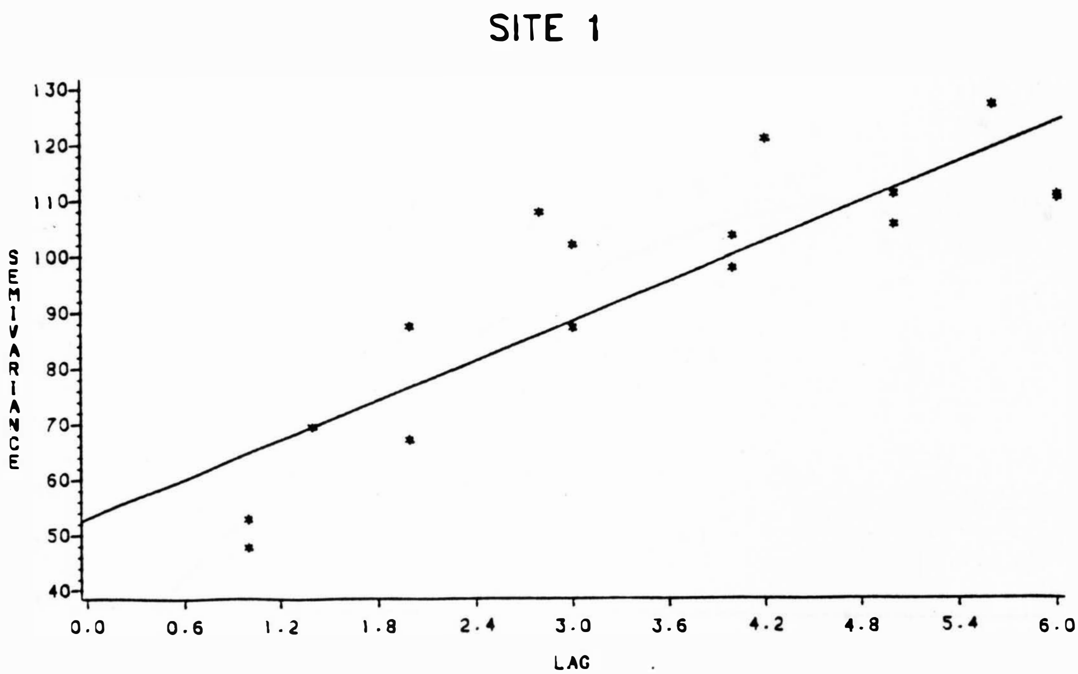


Figure 5. Directional semivariograms for site 1.

Table 1. Parameters of the semivariogram models for site 1.

		r^2
linear:	$\gamma(h) = 52.9 + 11.9h$	0.75
quadratic	$\gamma(h) = 21.2 + 35.3h - 3.4h^2$	0.87

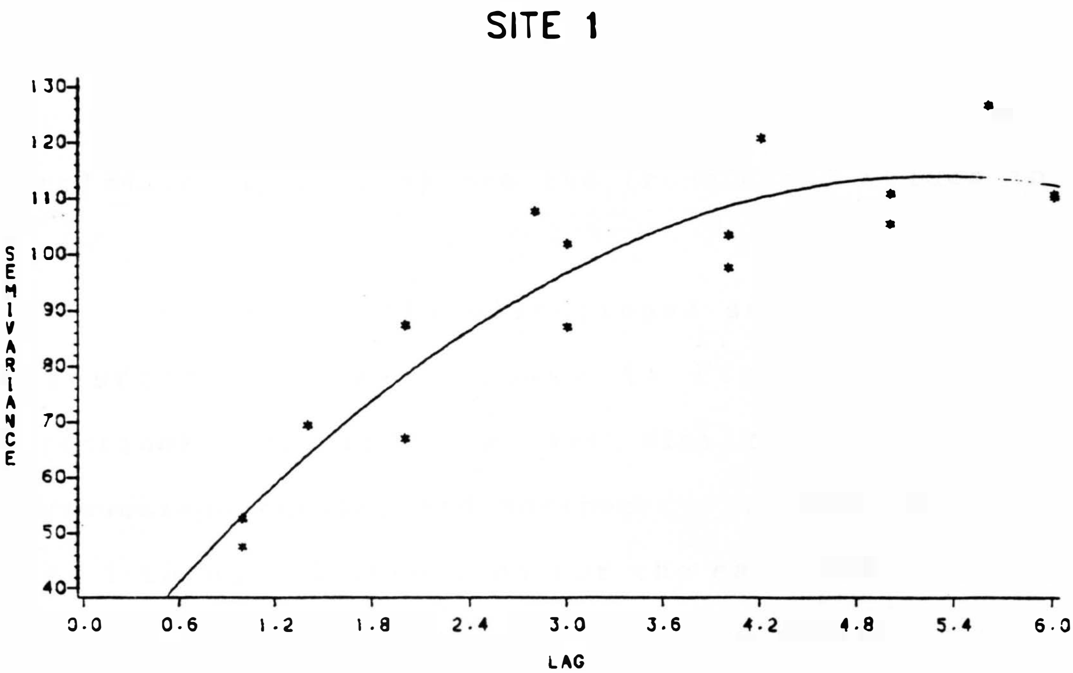
	range (meters)	sill	nugget effect
linear	91.4	124.3	52.9
quadratic	79.2	112.8	21.2



$$\gamma(h) = 52.9 + 11.9h$$

$$r^2 = 0.75$$

Figure 6. Linear semivariogram model for site 1.



$$\gamma(h) = 21.2 = 35.3h - 3.4h^2$$

$$r^2 = 0.87$$

Figure 7. Quadratic semivariogram model for site 1.

Site 2

The original test values for phosphorus at site 2 are shown in Figure 8. The average value is 14.5 mg/kg and the standard deviation is 8.1. The outlier values are circled in Figure 8 as are the transformed values in Figure 9.

A graph of the directional semivariograms for the transformed data is shown in Figure 10. The three directional semivariograms most similar were the east-west, northwest-southeast, and northeast-southwest semivariograms. Lags 1 through 4 were used for the east-west direction and lags 1.4 through 4.2 were used for the other two directions.

Linear and quadratic models were fitted to those semivariograms. Table 2 gives the parameters of the semivariogram models for site 2.

Figure 11 represents the linear model, and Figure 12 represents the quadratic model. The quadratic model with an r^2 value of 0.84 gives a better representation of the spatial relationship than does the linear model. A spatial relationship between samples separated by less than 50.3 meters was found with the quadratic model.

SITE 2
mg Phosphorus/kg Soil
Original Values

12	7	11	10	12	10	10	35	33	14	8	26	14	9	16
16	10	12	13	10	10	10	15	12	9	38	21	13	11	16
21	12	8	9	9	6	22	24	13	9	18	10	9	25	16
20	8	12	9	8	9	15	10	15	15	8	12	18	12	16
20	20	13	17	12	20	16	18	10	21	10	25	12	16	10
26	29	13	19	17	12	15	8	6	30	18	17	10	12	10
15	25	22	8	9	16	25	13	14	77	26	20	10	13	14
20	28	21	10	10	13	15	11	13	16	22	17	10	8	20
11	19	13	17	11	12	20	13	29	11	11	10	12	12	12
19	10	3	4	9	10	31	10	18	11	11	11	8	18	15
13	9	1	3	9	39	18	11	20	20	10	9	14	14	12
11	13	5	6	10	45	35	8	19	10	9	8	10	12	13
16	13	10	8	11	15	16	14	16	35	11	9	13	9	7
12	10	7	11	7	25	24	13	10	28	16	9	9	13	3
11	10	10	3	14	12	28	14	8	14	13	11	11	11	12

Figure 8. Original soil phosphorus test values for site 2.

SITE 2
mg Phosphorus/kg Soil
Transformed Values

12	7	11	10	12	10	10	12	13	14	8	26	14	9	16
16	10	12	13	10	10	10	15	12	9	38	21	13	11	16
21	12	8	9	9	6	22	24	13	9	18	10	9	25	16
20	8	12	9	8	9	15	10	15	15	8	12	18	12	16
20	20	13	17	12	20	16	18	10	21	10	25	12	16	10
26	29	13	19	17	12	15	8	6	30	18	17	10	12	10
15	25	22	8	9	16	25	13	14	18	26	20	10	13	14
20	28	21	10	10	13	15	11	13	16	22	17	10	8	20
11	19	13	17	11	12	20	13	29	11	11	10	12	12	12
19	10	3	4	9	10	31	10	18	11	11	11	8	18	15
13	9	1	3	9	39	18	11	20	20	10	9	14	14	12
11	13	5	6	10	45	35	8	19	10	9	8	10	12	13
16	13	10	8	11	15	16	14	16	35	11	9	13	9	7
12	10	7	11	7	25	24	13	10	28	16	9	9	13	3
11	10	10	3	14	12	28	14	8	14	13	11	11	11	12

Figure 9. Transformed soil phosphorus test values for site 2.

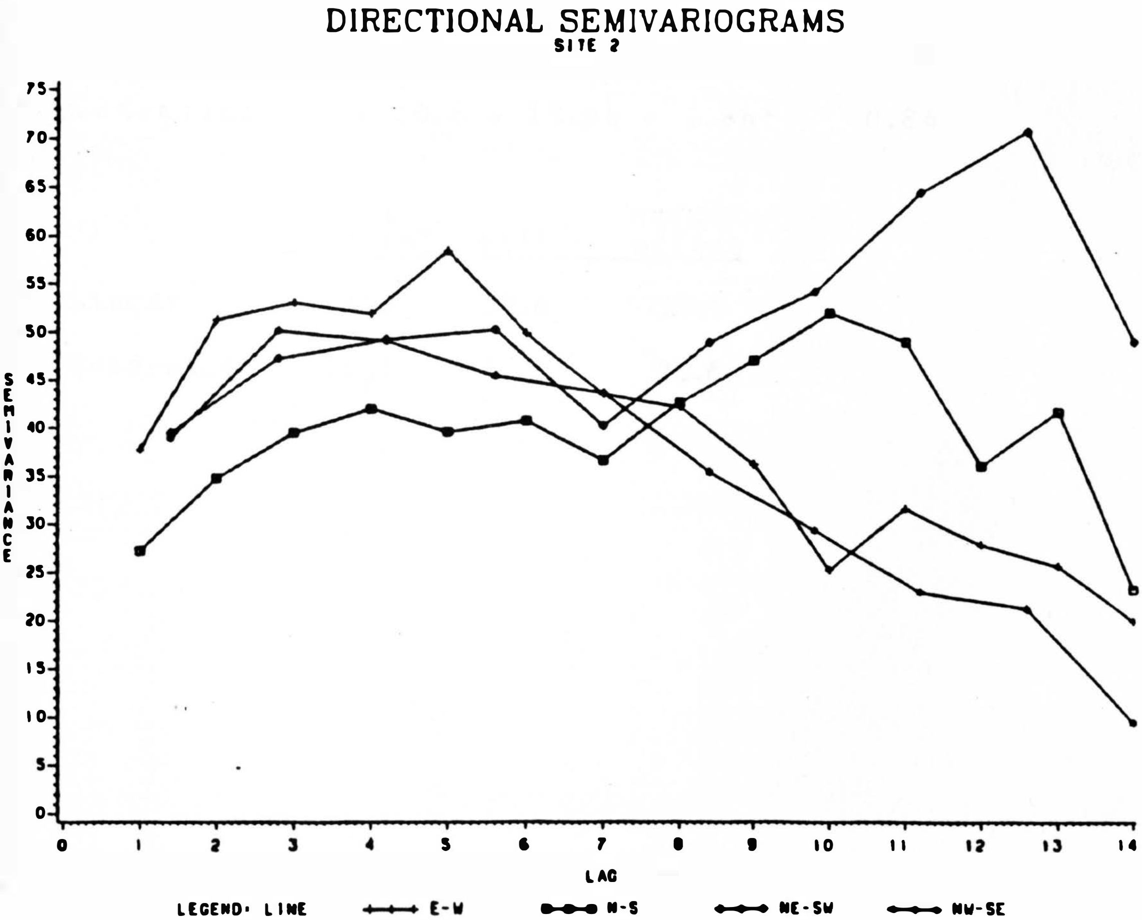
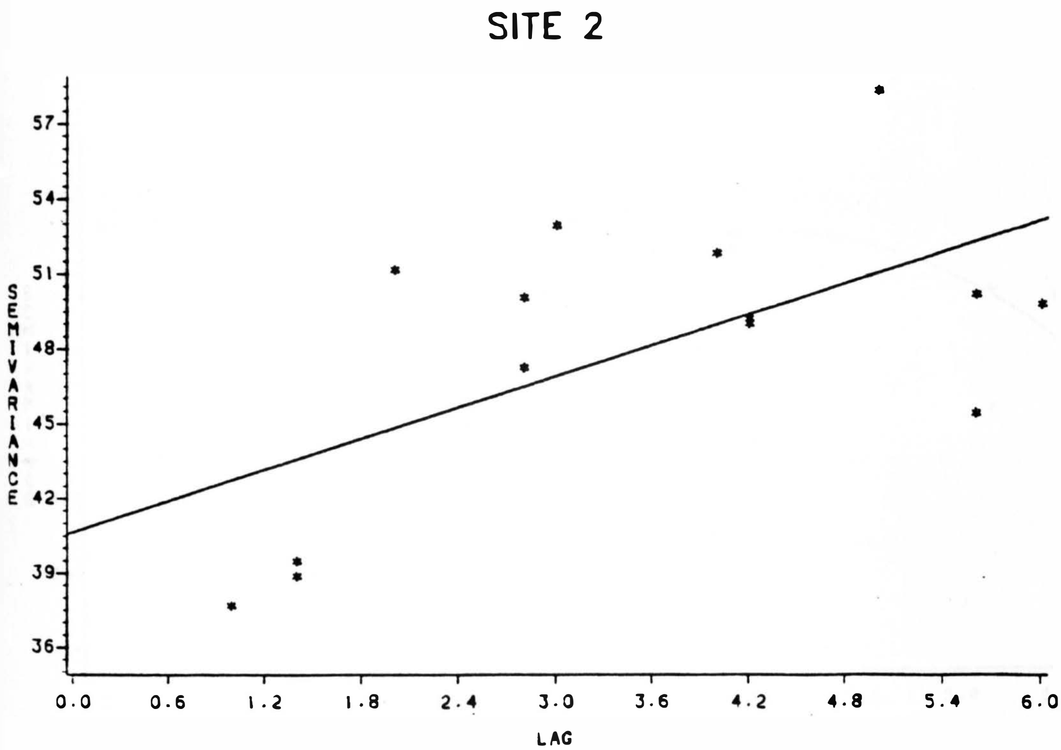


Figure 10. Directional semivariograms for site 2.

Table 2. Parameters of the semivariogram models of site 2.

		r^2
Linear:	$\gamma(h) = 36.9 + 3.7h$	0.58
Quadratic:	$\gamma(h) = 20.6 + 18.5h - 2.8h^2$	0.84

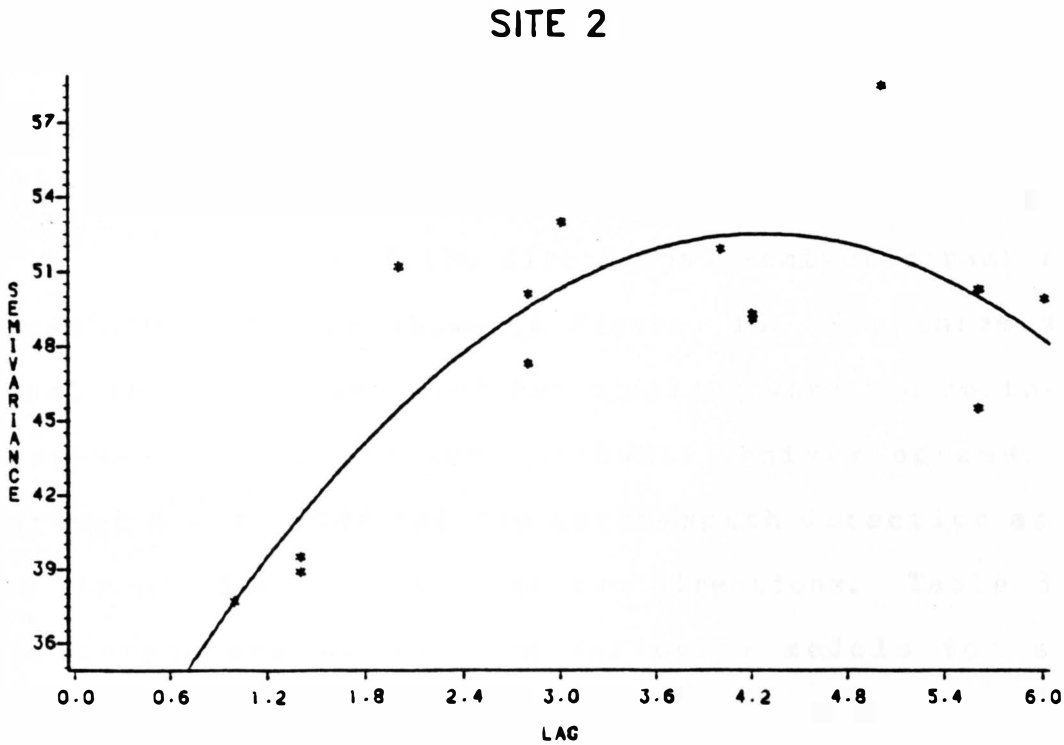
	range (meters)	sill	nugget effect
Linear	64.0	52.4	36.9
Quadratic	50.3	51.2	20.6



$$\gamma(h) = 36.9 + 3.7h$$

$$r^2 = 0.58$$

Figure 11. Linear semivariogram model for site 2.



$$\gamma(h) = 20.6 + 18.5h - 2.8h^2$$

$$r^2 = 0.84$$

Figure 12. Quadratic semivariogram model for site 2.

Site 3

The original test values for phosphorus at site 3 are shown in Figure 13. The average value is 10.6 mg/kg and the standard deviation is 6.4. The outlier values are circled in Figure 13 as are the transformed values in Figure 14.

A graph of the directional semivariograms for the transformed data is shown in Figure 15. The three directional semivariograms used for modeling were the north-south, east-west, and northeast-southwest semivariograms. Lags 1 through 4 were used for the north-south direction and lags 1.4 through 2.8 for the other two directions. Table 3 gives the parameters of the semivariogram models for site 3. Figure 16 represents the linear model, and Figure 17 represents the quadratic model.

This site had low semivariance values, low sills, low nugget effects, and low r^2 values for both models. The low r^2 values indicate a possible pure nugget effect. This would mean that there is a weak relationship between samples gathered at the ranges given above. The range of the linear model is 61.0 meters, but the r^2 value of this model is only 0.44 which indicates a weak relationship between samples separated by that distance. A shorter sampling distance may have revealed a more substantial pattern. An interesting aspect of the directional semivariograms is all four directional semivarigrams seem to be cyclic with all four cycles out of phase with one another. It has the appearance of

SITE 3
mg Phosphorus/kg Soil
Original Values

7	11	5	8	8	7	7	10	8	10	10	13	7	5	6
4	8	8	24	7	7	7	13	9	6	11	9	6	5	5
23	8	10	10	9	13	9	7	11	10	12	7	6	6	7
9	12	10	11	11	11	10	12	12	11	10	12	12	13	9
9	9	9	10	9	9	6	6	7	6	9	11	11	7	7
7	7	5	6	9	7	5	5	6	4	5	8	7	8	13
9	9	5	13	8	7	6	8	12	8	12	14	16	9	7
11	11	11	13	10	9	10	13	9	9	12	12	24	11	10
7	5	6	7	8	5	9	6	8	9	10	10	7	7	8
10	11	9	12	6	7	7	53	13	66	18	6	5	12	10
14	13	7	9	4	4	11	16	16	22	12	7	13	9	9
11	13	21	11	11	10	17	14	12	8	7	11	8	13	9
9	6	10	10	11	18	12	12	15	9	10	8	9	12	13
8	9	8	8	12	13	39	14	11	9	13	12	12	12	12
8	9	9	9	10	18	36	17	17	8	9	17	16	13	16

Figure 13. Original soil phosphorus test values for site 3.

SITE 3
mg Phosphorus/kg Soil
Transformed Values

7	11	5	8	8	7	7	10	8	10	10	13	7	5	6
4	8	8	8	7	7	7	13	9	6	11	9	6	5	5
23	8	10	10	9	13	9	7	11	10	12	7	6	6	7
9	12	10	11	11	11	10	12	12	11	10	12	12	13	9
9	9	9	10	9	9	6	6	7	6	9	11	11	7	7
7	7	5	6	9	7	5	5	6	4	5	8	7	8	13
9	9	5	13	8	7	6	8	12	8	12	14	16	9	7
11	11	11	13	10	9	10	13	9	9	12	12	24	11	10
7	5	6	7	8	5	9	6	8	9	10	10	7	7	8
10	11	9	12	6	7	7	11	13	14	18	6	5	12	10
14	13	7	9	4	4	11	16	16	22	12	7	13	9	9
11	13	21	11	11	10	17	14	12	8	7	11	8	13	9
9	6	10	10	11	18	12	12	15	9	10	8	9	12	13
8	9	8	8	12	13	14	14	11	9	13	12	12	12	12
8	9	9	9	10	18	15	17	17	8	9	17	16	13	16

Figure 14. Transformed soil phosphorus test values for site 3.

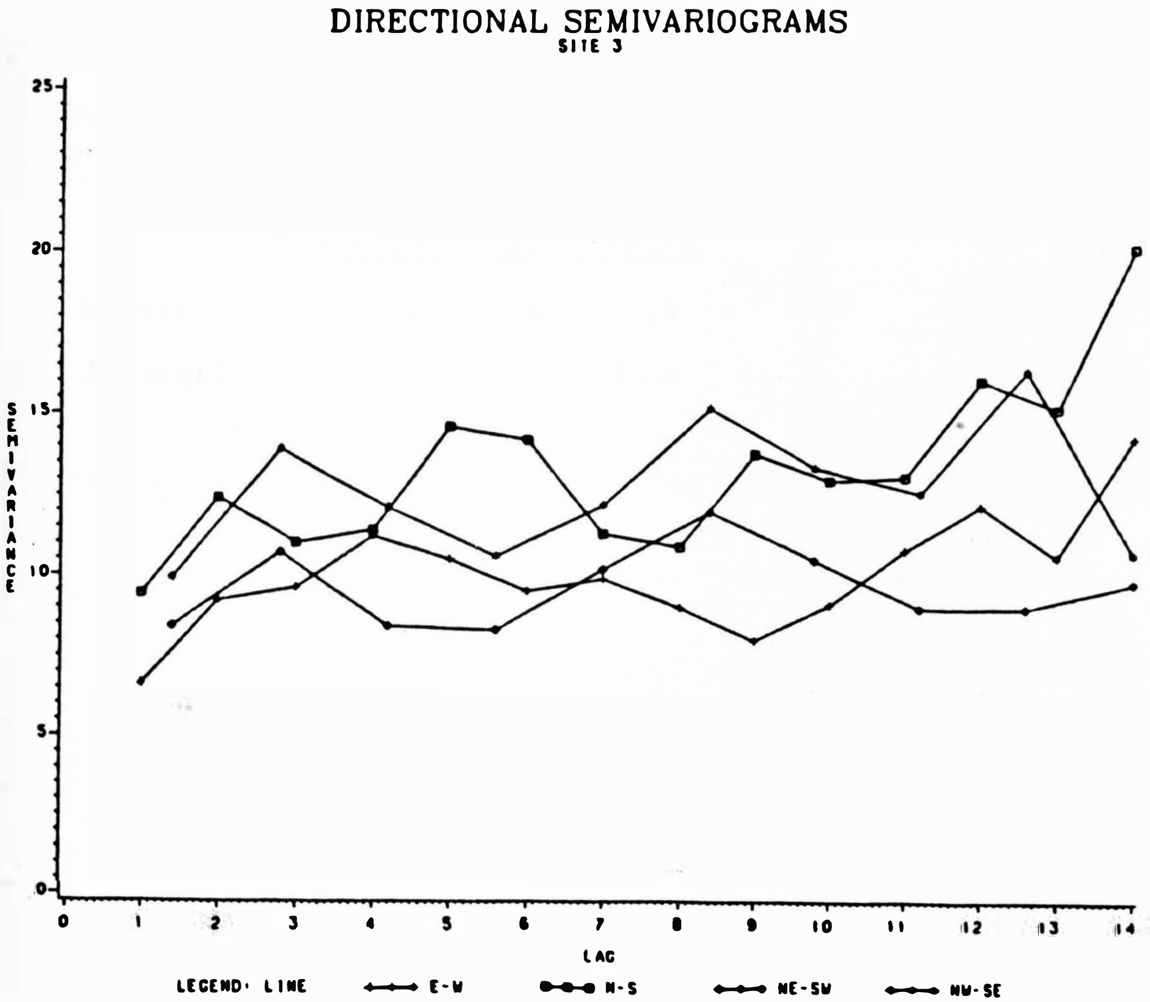
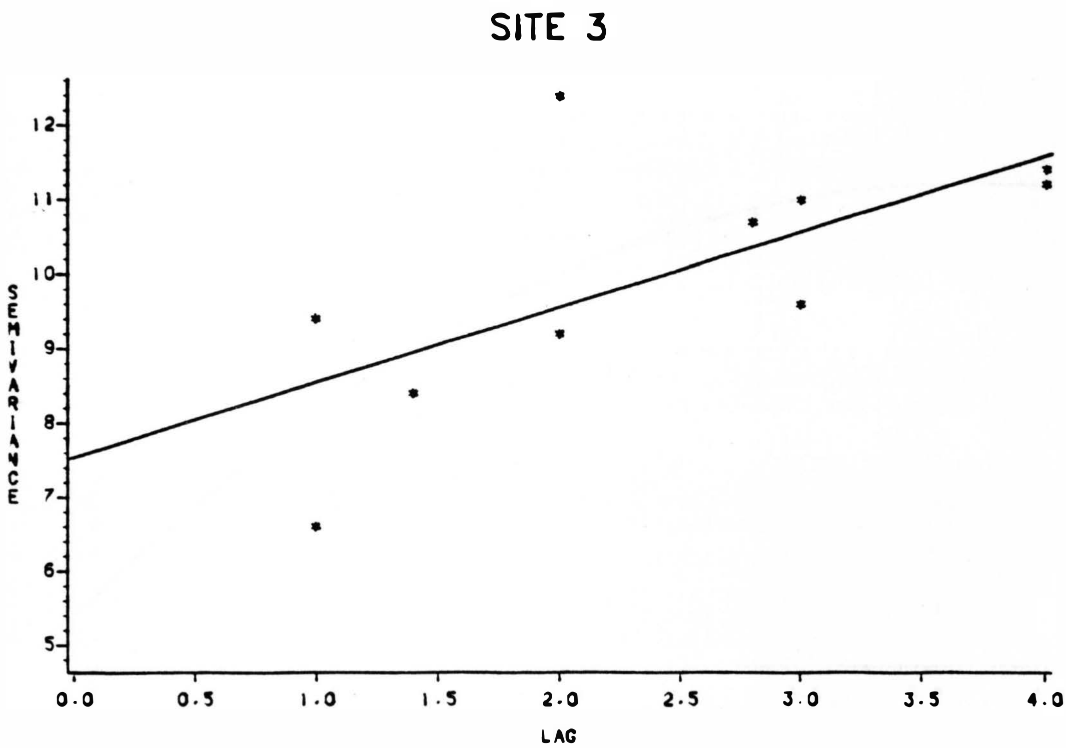


Figure 15. Directional semivariograms for site 3.

Table 3. Parameters of the semivariogram models for site 3.

		r^2
Linear:	$\gamma(h) = 7.5 + 1.0h$	0.44
Quadratic:	$\gamma(h) = 5.4 + 3.1h - 0.4h^2$	0.51

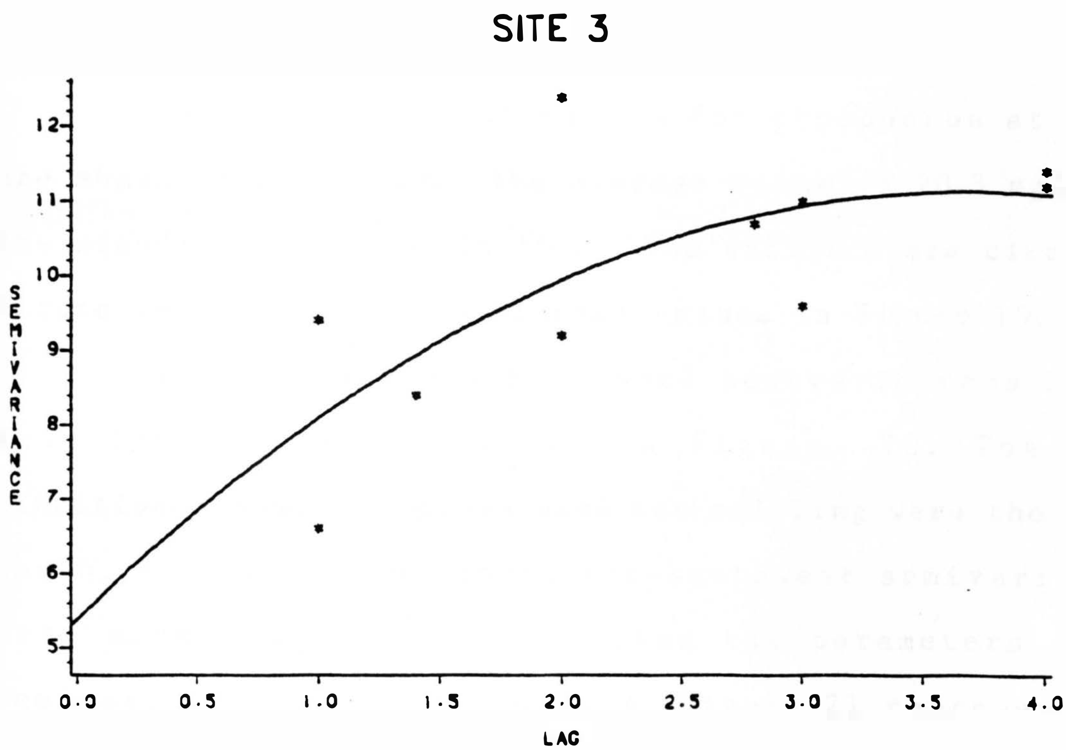
	range (meters)	sill	nugget effect
Linear	61.0	11.5	7.5
Quadratic	59.5	11.4	5.4



$$\gamma(h) = 7.5 + 1.0h$$

$$r^2 = 0.44$$

Figure 16. Linear semivariogram model for site 3.



$$\gamma(h) = 5.4 + 3.1h - 0.4h^2$$

$$r^2 = 0.51$$

Figure 17. Quadratic semivariogram model for site 3.

randomly scattered points, resembling a pure nugget effect.

Site 4

The original test values for phosphorus at site 4 are shown in Figure 18. The average value is 20.3 mg/kg and the standard deviation is 10.2. The outliers are circled in Figure 18 as are the transformed values in Figure 19.

A graph of the directional semivariograms for the transformed data is shown in Figure 20. The three directional semivariograms used for modeling were the north-south, east-west, and northeast-southwest semivariograms over seven lags. Table 4 gives the parameters of the semivariogram models for site 4. Figure 21 represents the linear model, and Figure 22 represents the quadratic model. A spatial relationship between samples separated by less than 106.7 meters was found.

SITE 4
mg Phosphorus/kg Soil
Original Values

3	3	3	4	8	5	6	19	9	30	7	5	8	1	12
10	9	42	7	11	9	6	18	13	21	16	20	12	16	10
13	15	18	10	10	16	10	19	26	48	14	22	19	26	13
16	12	9	9	16	16	13	11	7	7	18	11	13	18	14
23	14	26	18	16	13	28	28	12	21	29	25	17	25	15
11	7	10	10	13	23	17	45	7	27	13	16	11	10	27
35	26	31	42	35	42	31	19	24	21	20	13	11	18	14
19	18	53	35	19	30	13	9	19	9	16	12	15	13	21
42	38	33	43	36	38	18	12	23	18	21	21	14	19	35
23	30	22	19	19	18	12	20	26	23	20	12	22	20	32
25	29	35	16	18	22	17	13	12	18	13	19	8	16	27
29	21	24	20	13	11	13	21	27	32	27	22	15	17	11
21	12	10	8	14	26	38	36	40	24	33	25	13	24	21
24	24	30	39	31	40	32	36	38	23	28	24	18	18	2
32	30	35	35	38	31	47	45	23	35	24	13	13	24	20

Figure 18. Original soil phosphorus test values for site 4.

SITE 4
mg Phorphorus/kg Soil
Transformed Values

4	3	3	4	8	5	6	19	9	30	7	5	8	1	12
10	9	9	7	11	9	6	18	13	21	16	20	12	16	10
13	15	18	10	10	16	10	19	26	15	14	22	19	26	13
16	12	9	9	16	16	13	11	7	7	18	11	13	18	14
23	14	26	18	16	13	28	28	12	21	29	25	17	25	15
11	7	10	10	13	23	17	45	7	27	13	16	11	10	27
35	26	31	42	35	42	31	19	24	21	20	13	11	18	14
19	18	53	35	19	30	13	9	19	9	16	12	15	13	21
42	38	33	43	36	38	18	12	23	18	21	21	14	19	35
23	30	22	19	19	18	12	20	26	23	20	12	22	20	32
25	29	35	16	18	22	17	13	12	18	13	19	8	16	27
29	21	24	20	13	11	13	21	27	32	27	22	15	17	11
21	12	10	8	14	26	38	36	40	24	33	25	13	24	21
24	24	30	39	31	40	32	36	38	23	28	24	18	18	2
32	30	35	35	38	31	35	32	23	35	24	13	13	24	20

Figure 19. Transformed soil phosphorus test values for site 4.

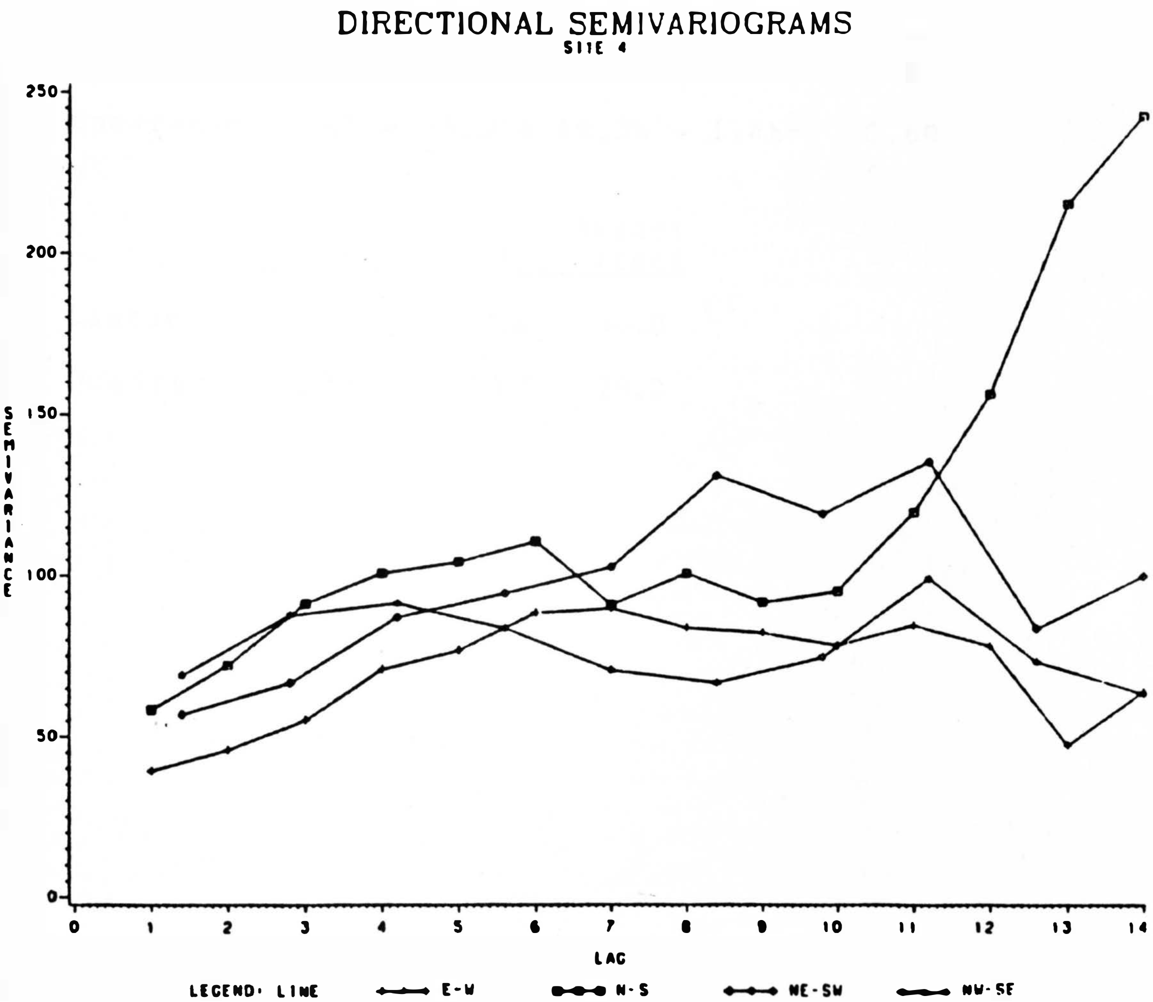
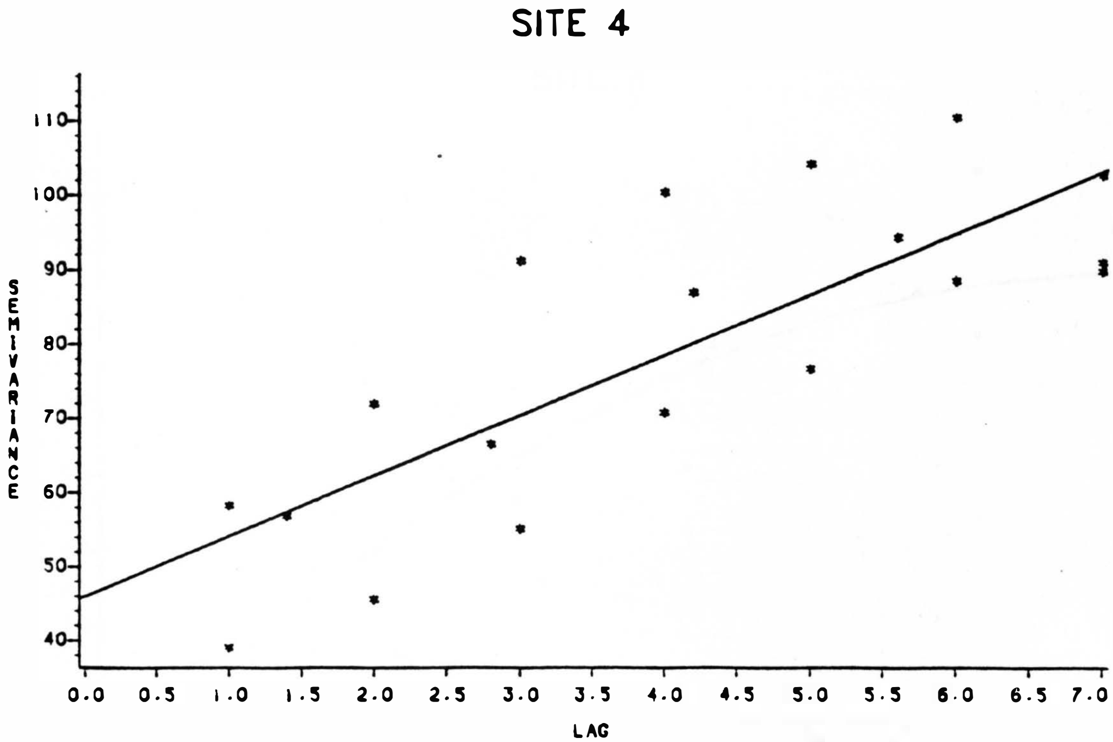


Figure 20. Directional semivariograms for site 4.

Table 4. Paramters of the semivariogram models for site 4.

		r^2
Linear:	$\gamma(h) = 46.0 + 8.2h$	0.63
Quadratic:	$\gamma(h) = 29.0 + 19.3h - 1.4h^2$	0.69

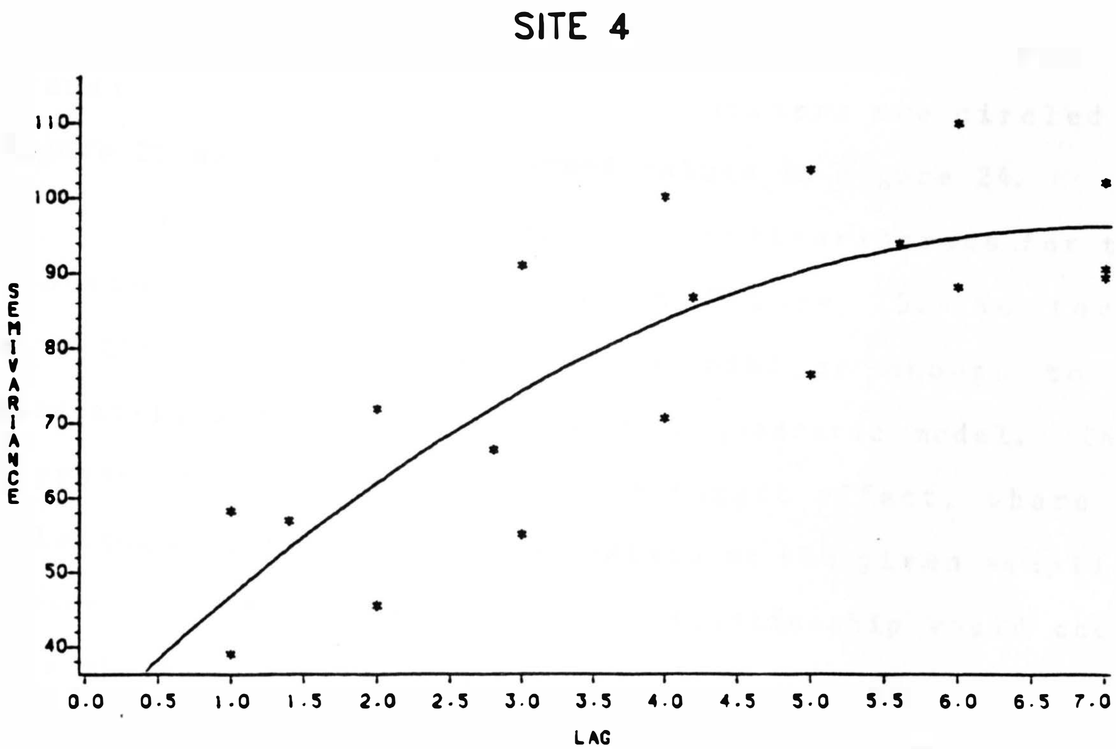
	range (meters)	sill	nugget effect
Linear	106.7	103.4	46.0
Quadratic	105.1	95.5	29.0



$\gamma(h) = 46.0\ 8.2h$

$r^2 = 0.63$

Figure 21. Linear semivariogram model for site 4.



$$\gamma(h) = 29.0 + 19.3h - 1.4h^2$$

$$r^2 = 0.69$$

Figure 22. Quadratic semivariogram model for site 4.

Site 5

The original test values for phosphorus at site 5 is shown in Figure 23. The average is 18.9 mg/kg and the standard deviation is 11.6. The outliers are circled in Figure 23 as are the transformed values in Figure 24.

A graph of the directional semivariograms for the transformed data is shown in Figure 25. No three directional semivariograms were similar enough to be adequately described by a linear or quadratic model. This suggests the presence of a pure nugget effect, where no relationship between samples exists at the given sampling distances. It is possible that a relationship would occur at a shorter sampling distance.

Graphs depicting linear and quadratic models based on all four directional semivariograms over 14 lags are shown in Figures 26 and 27. The semivariance points are scattered about the graphs giving a good illustration of the gold nugget effect.

		r^2
linear:	$\gamma(h) = 33.3 + 0.74h$	0.11
quadratic:	$\gamma(h) = 34.0 + 0.48h + 0.017h^2$	0.11

SITE 5
mg Phosphorus/kg Soil
Original Values

10	11	26	20	14	28	18	17	20	32	17	77	12	26	20
10	7	25	32	24	20	17	14	17	16	17	11	17	34	14
11	18	26	24	17	42	30	20	24	18	19	12	12	25	14
15	20	33	51	17	21	22	20	24	13	16	18	12	18	24
7	25	27	22	13	19	21	15	23	22	29	20	10	14	10
10	11	24	8	14	18	18	25	18	20	16	13	22	23	100
10	10	35	10	9	24	16	19	19	15	16	13	15	26	11
22	7	29	12	9	18	11	21	16	15	14	13	12	15	8
18	8	32	47	6	24	9	18	16	12	9	11	9	13	10
13	8	29	21	11	17	27	16	14	23	11	15	8	13	12
14	12	25	26	14	17	11	20	25	17	13	8	14	12	17
24	10	28	17	18	100	12	14	16	16	30	12	13	20	21
11	9	18	17	22	20	19	36	14	16	27	13	8	13	18
10	9	22	17	19	30	14	23	26	13	13	16	11	29	42
17	11	22	15	9	22	16	13	11	14	12	16	20	52	35

Figure 23. Original soil phosphorus test values for site 5.

SITE 5
mg Phosphorus/kg Soil
Transformed Values

10	11	26	20	14	28	18	17	20	32	17	15	12	26	20
10	7	25	32	24	20	17	14	17	16	17	11	17	34	14
11	18	26	24	17	21	30	20	24	18	19	12	12	25	14
15	20	33	22	17	21	22	20	24	13	16	18	12	18	24
7	25	27	22	13	19	21	15	23	22	29	20	10	14	10
10	11	24	8	14	18	18	25	18	20	16	13	22	23	17
10	10	35	10	9	24	16	19	19	15	16	13	15	26	11
22	7	29	12	9	18	11	21	16	15	14	13	12	15	8
18	8	32	47	6	24	9	18	16	12	9	11	9	13	10
13	8	29	21	11	17	27	16	14	23	11	15	8	13	12
14	12	25	25	14	17	11	20	25	17	13	8	14	12	17
24	10	28	17	18	17	12	14	16	16	30	12	13	20	21
11	9	18	17	22	20	19	36	14	16	27	13	8	13	18
10	9	22	17	19	30	14	23	26	13	13	16	11	29	24
17	11	22	15	9	22	16	13	11	14	12	16	20	24	35

Figure 24. Transformed soil phosphorus test values for site 5.

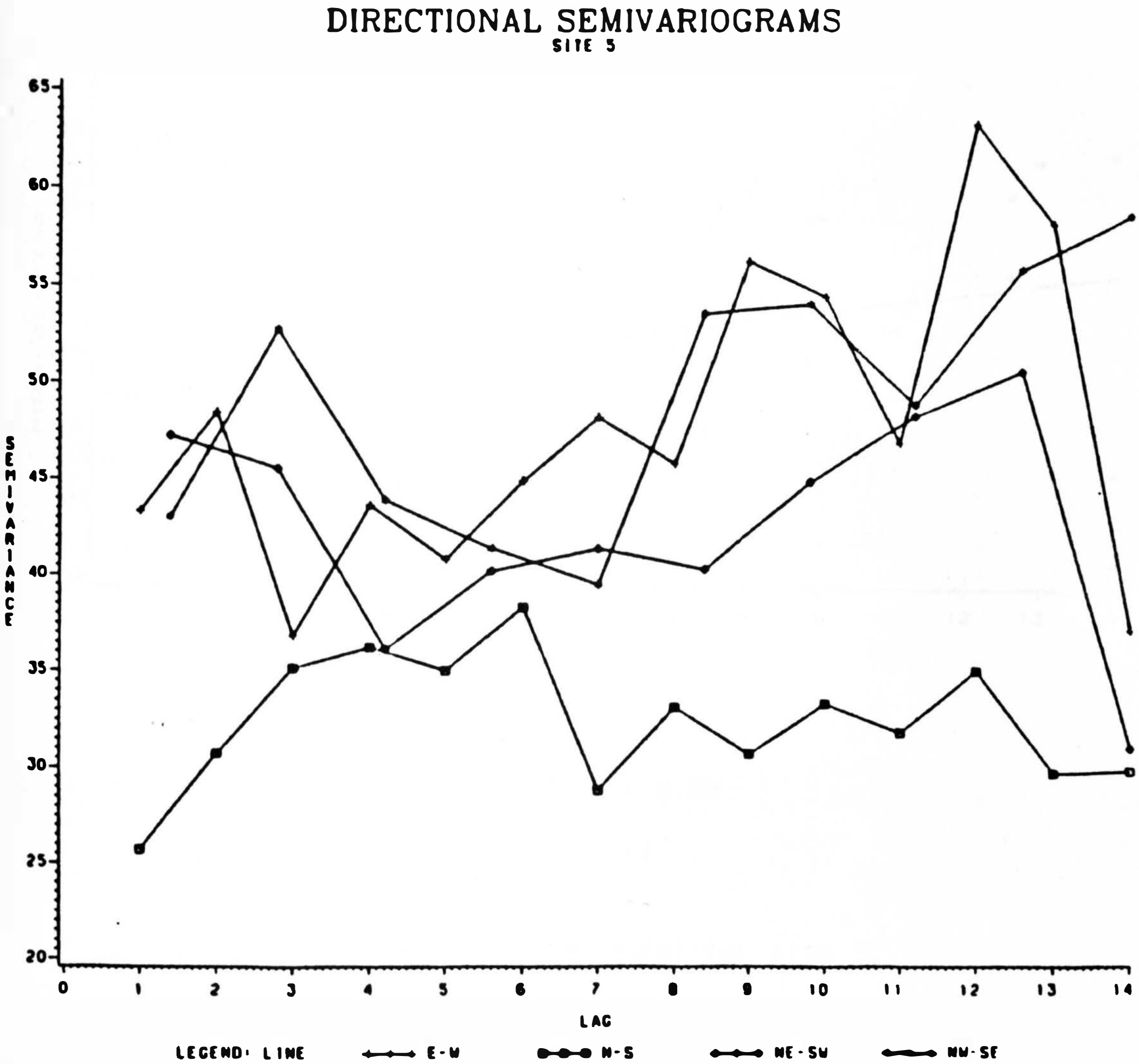
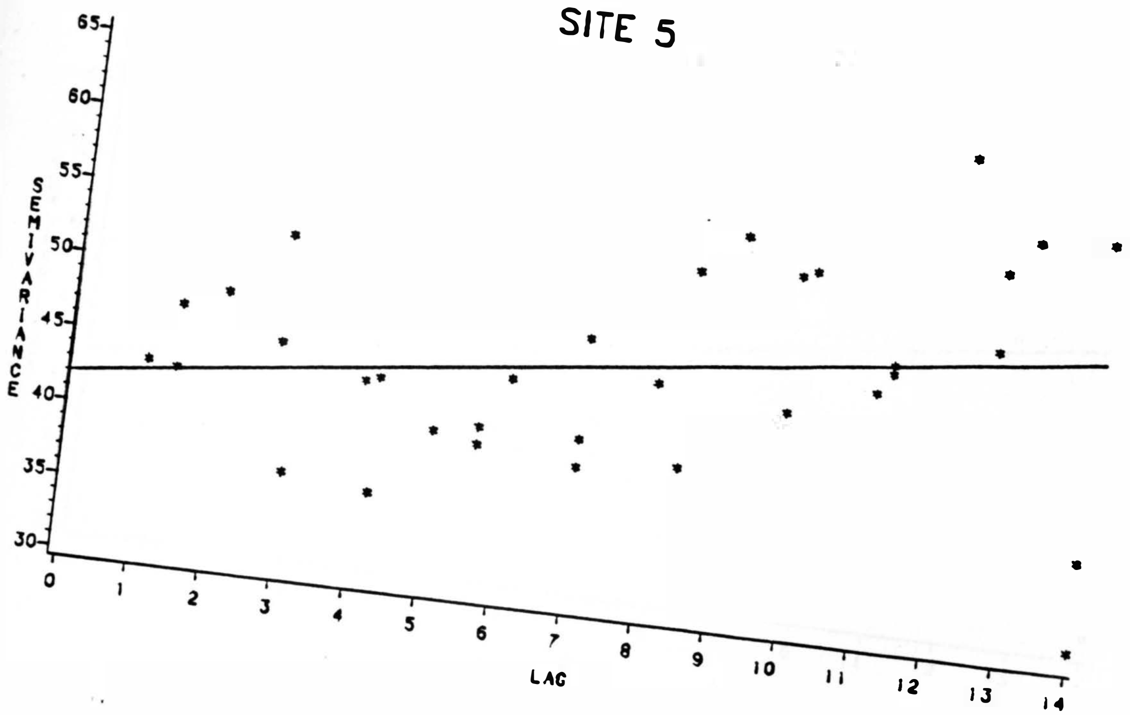


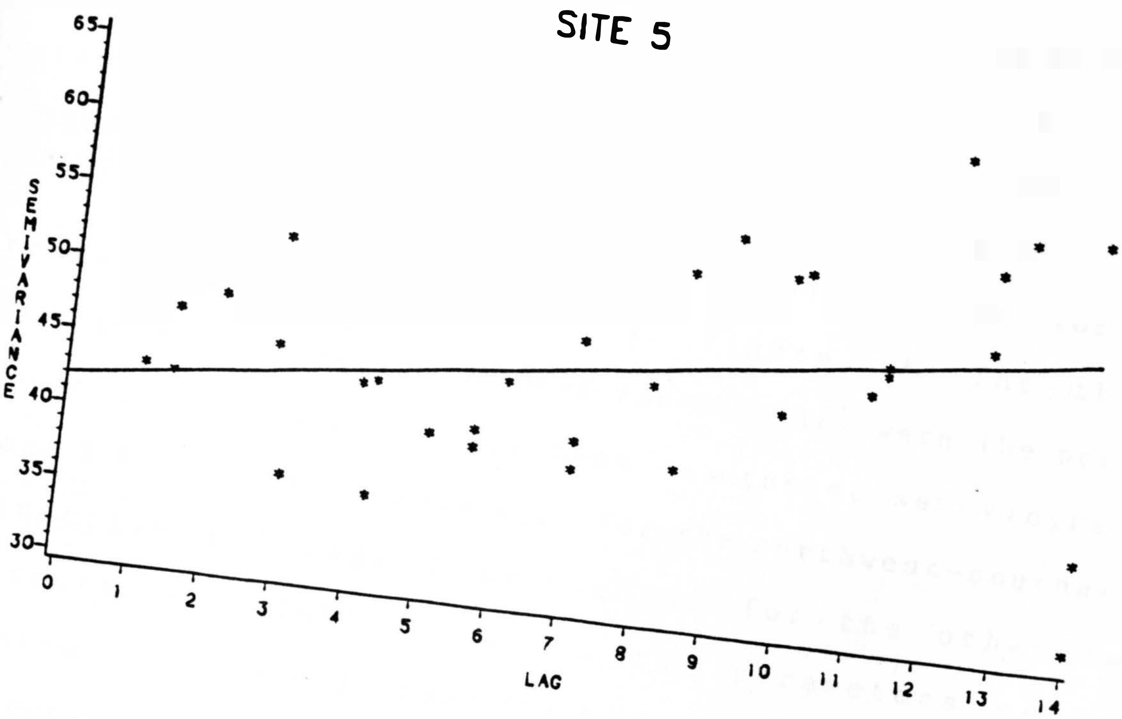
Figure 25. Directional semivariograms for site 5.



$$\gamma(h) = 33.3 + 0.7h$$

$$r^2 = 0.11$$

Figure 26. Linear semivariogram model for site 5.



$$\gamma(h) = 34.0 + 0.48h + 0.017h^2$$

$$r^2 = 0.11$$

Figure 27. Quadratic semivariogram model for site 5.

Site 6

The original test values for phosphorus at site 6 are shown in Figure 28. The average is 26.3 mg/kg and the standard deviation is 20.1. The outliers are circled in Figure 28 as are the transformed values in Figure 29.

A graph of the directional semivariograms for the transformed data is shown in Figure 30. The three directional semivarigrams used for modeling were the north-south, east-west, and northwest-southeast semiviograms. Lags 1.4 through 9.8 were used for the northwest-southeast direction and lags 1 through 10 for the other two directions. Table 5 gives the parameters of the semivariogram models for site 6. Figure 31 represents the linear model, and Figure 32 represents the quadratic model. Site 6 had the longest range of all sites evaluated. Both models adequately represent the spatial relationship of phosphorus at site 6.

The first derivative of the quadratic model yielded a negative term when solved for h due to a positive value for the h squared term in the formula. Since there cannot be a negative distance, it was disregarded and the range becomes equal to the largest lag used in the model.

SITE 6
mg Phosphorus/kg Soil
Original Values

64	44	49	38	47	35	28	34	36	40	35	57	66	68	35
51	99	49	35	57	51	44	27	24	28	36	22	25	49	33
77	44	36	25	47	31	22	24	20	32	18	13	17	14	16
99	38	33	35	52	35	35	22	23	28	23	20	18	24	23
43	39	45	28	45	22	25	39	27	21	20	16	20	23	45
45	33	35	29	51	31	27	26	22	21	14	18	15	15	24
30	22	31	33	49	31	27	30	21	10	11	14	13	20	19
33	25	22	29	35	26	45	26	27	17	17	14	11	11	14
24	19	45	42	35	24	24	16	20	11	12	9	13	11	12
27	20	23	22	16	18	11	16	21	13	11	9	12	8	10
20	15	11	18	14	11	12	16	13	13	13	11	10	10	10
14	9	11	10	15	11	18	16	7	9	9	18	100	8	7
43	18	13	11	22	16	12	10	13	12	13	12	8	8	11
21	18	20	20	22	35	19	25	15	31	100	9	13	18	18
24	13	25	26	24	23	15	18	16	19	16	20	18	16	20

Figure 28. Original soil phosphorus test values for site 6.

SITE 6
mg Phosphorus/kg Soil
Transformed Values

64	44	49	38	47	35	28	34	36	40	35	57	66	42	35
51	99	49	35	57	51	44	27	24	28	36	22	25	49	33
77	44	36	25	47	31	22	24	20	32	18	13	17	14	16
99	38	33	35	52	35	35	22	23	28	23	20	18	24	23
43	39	45	28	45	22	25	39	27	21	20	16	20	23	45
45	33	35	29	51	31	27	26	22	21	14	18	15	15	24
30	22	31	33	49	31	27	30	21	10	11	14	13	20	19
33	25	22	29	35	26	45	26	27	17	17	14	11	11	14
24	19	45	42	35	24	24	16	20	11	12	9	13	11	12
27	20	23	22	16	18	11	16	21	13	11	9	12	8	10
20	15	11	18	14	11	12	16	13	13	13	11	10	10	10
14	9	11	10	15	11	18	16	7	9	9	18	11	8	7
43	18	13	11	22	16	12	10	13	12	13	12	8	8	11
21	18	20	20	22	35	19	25	15	31	17	9	13	18	18
24	13	25	26	24	23	15	18	16	19	16	20	18	16	20

Figure 29. Transformed soil phosphorus test values for site 6.

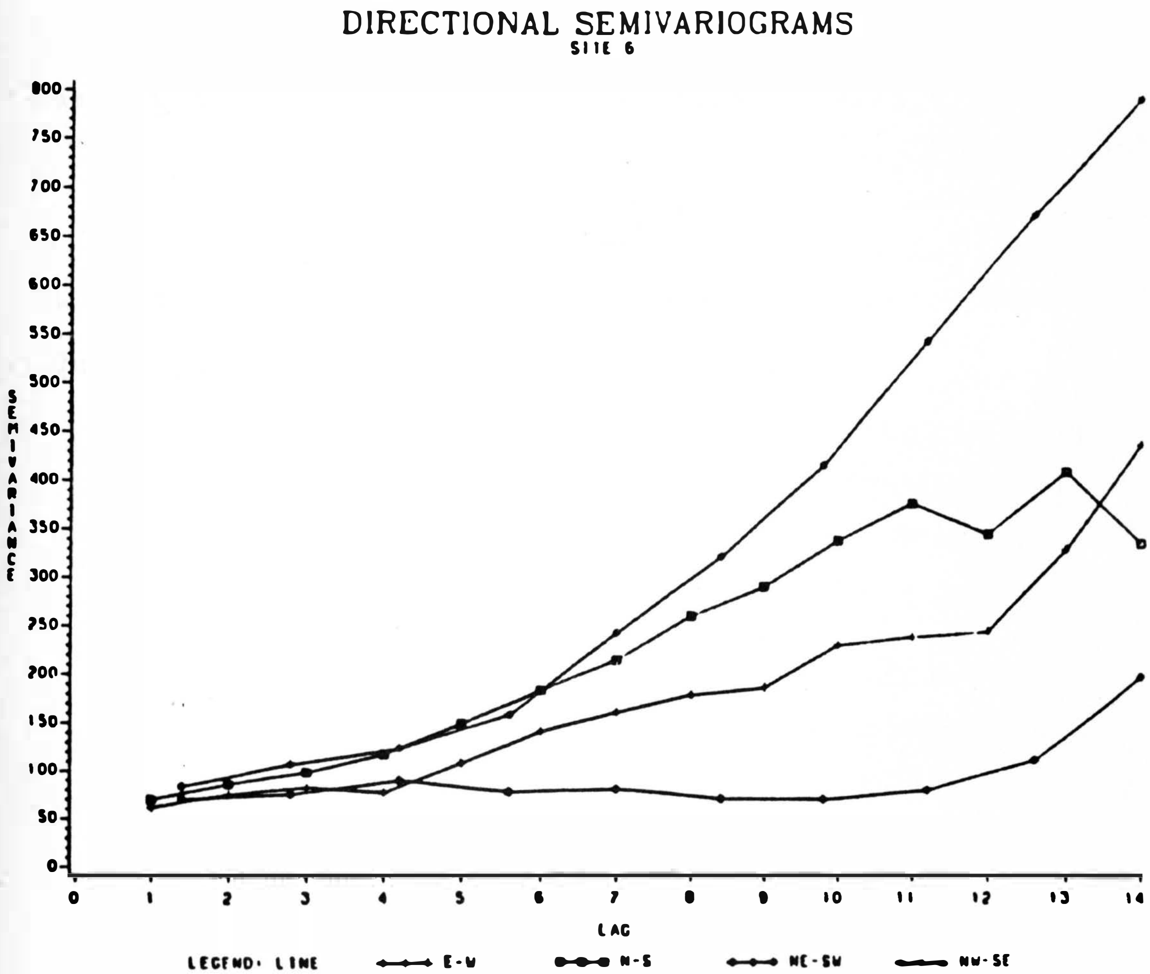
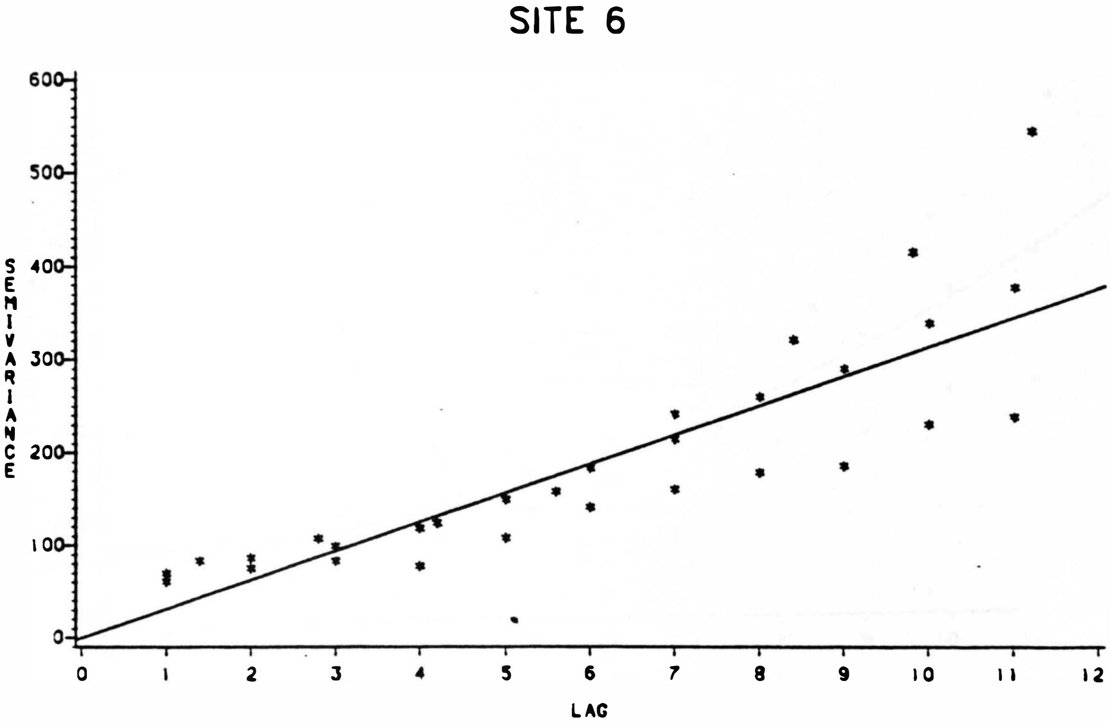


Figure 30. Directional semivariograms for site 6.

Table 5. Parameters of the semivariogram models for site 6.

		r^2
Linear:	$\gamma(h) = 9.5 + 20.4h$	0.73
Quadratic:	$\gamma(h) = 38.9 + 5.9h + 1.3h^2$	0.75

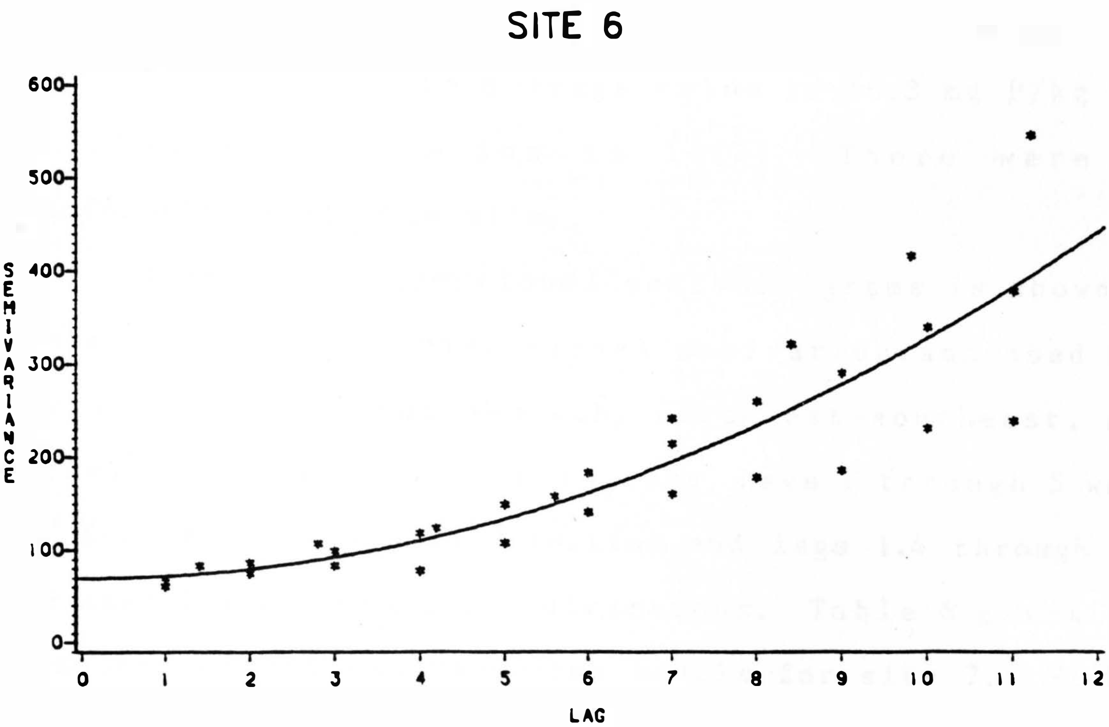
	range (meters)	sill	nugget effect
Linear	152.4	213.5	9.5
Quadratic	152.4	227.9	38.9



$$\gamma(h) = 9.5 + 20.4h$$

$$r^2 = 0.73$$

Figure 31. Linear semivariogram model for site 6.



$$\gamma(h) = 38.9 + 5.9h + 1.3h^2$$

$$r^2 = 0.75$$

Figure 32. Quadratic semivariogram model for site 6.

Site 7

The original test values for phophorus at site 7 are shown in Figure 33. The average value is 16.3 mg P/kg and the standard deviation is 12.7. There were no transformations at this site.

A graph of directional semivariograms is shown in Figure 34. The three directional semivariograms used for modeling were the north-south, northwest-southeast, and northeast-southwest semivariograms. Lags 1 through 5 were used for the north-south direction and lags 1.4 through 4.2 were used for the other two directions. Table 6 gives the parameters of the semivariogram models for site 7. Figure 35 represents the linear model, and Figure 36 represents the quadratic model. Both models have high r^2 values.

SITE 7

66	42	62	64	52	77	39	35	36	35	32	25	23	24
30	22	42	44	39	60	43	49	31	32	39	32	23	34
20	21	18	12	16	17	21	12	18	43	36	26	18	13
7	7	7	10	12	15	16	18	21	17	21	20	29	21
16	18	20	17	26	23	20	21	13	13	16	9	9	11
15	19	19	18	25	13	16	16	16	9	15	19	14	17
23	22	11	10	11	10	12	14	13	10	7	11	8	9
11	24	12	5	9	7	23	8	11	7	6	5	6	7
7	12	18	9	8	5	12	11	7	11	9	5	5	6
7	8	8	7	6	7	8	4	6	7	20	9	11	7
7	3	5	6	8	6	7	6	10	5	9	8	8	8
5	5	5	7	6	6	6	7	8	9	34	16	10	7
11	9	12	13	17	11	12	12	12	12	11	12	13	12
12	8	9	13	10	8	10	10	9	10	11	16	12	9

mg Phosphorus/kg Soil

Original values, no transformations were made on this site.

Figure 33. Original soil phosphorus test values for site 7.

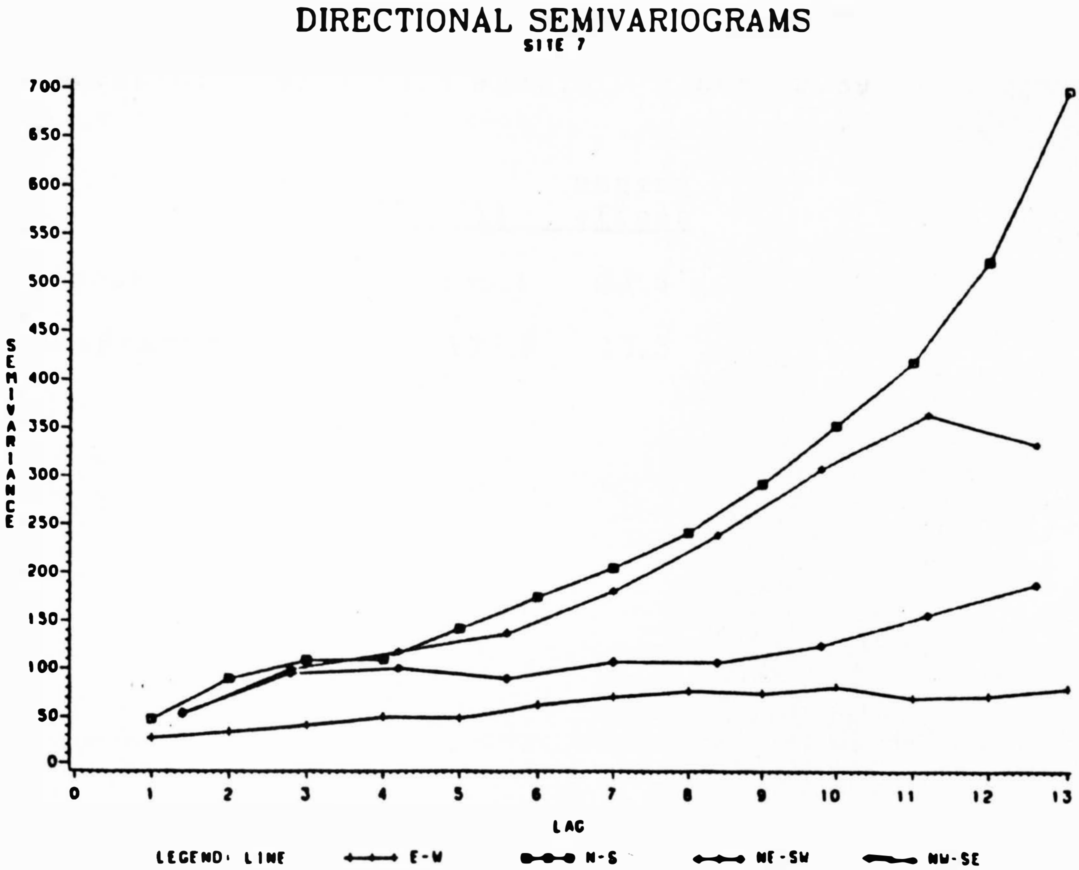
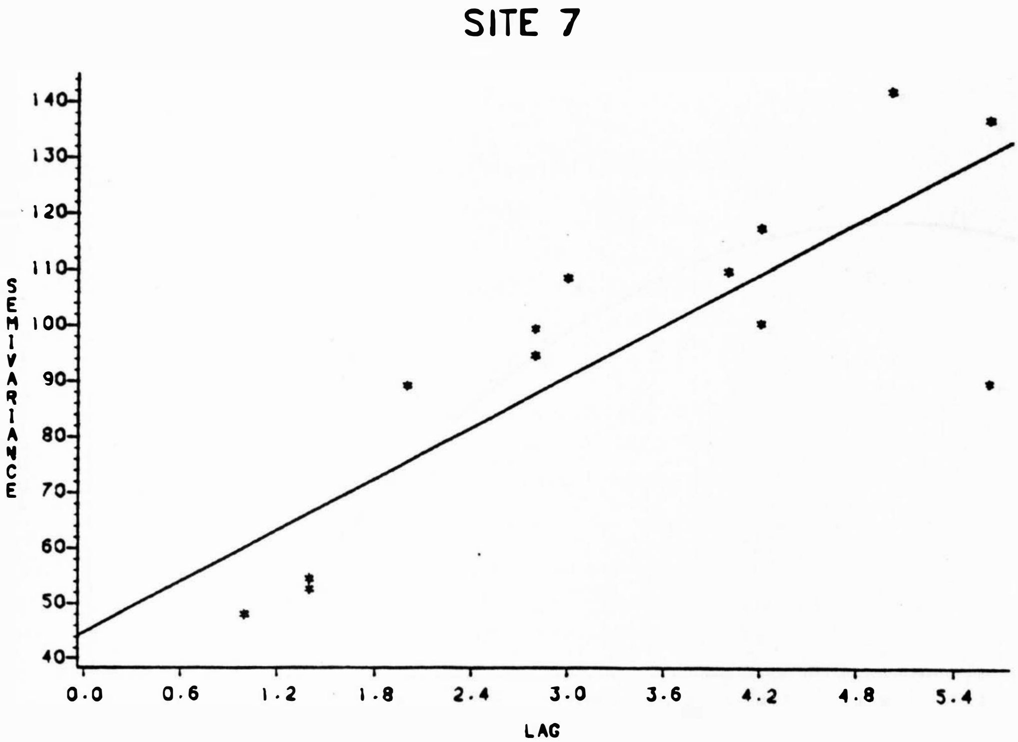


Figure 34. Directional semivariograms for site 7.

Table 6. Parameters of the semivariogram models for site 7.

		r^2
Linear:	$\gamma(h) = 32.6 + 20.7h$	0.87
Quadratic:	$\gamma(h) = 13.3 + 37.1h - 2.8h^2$	0.89

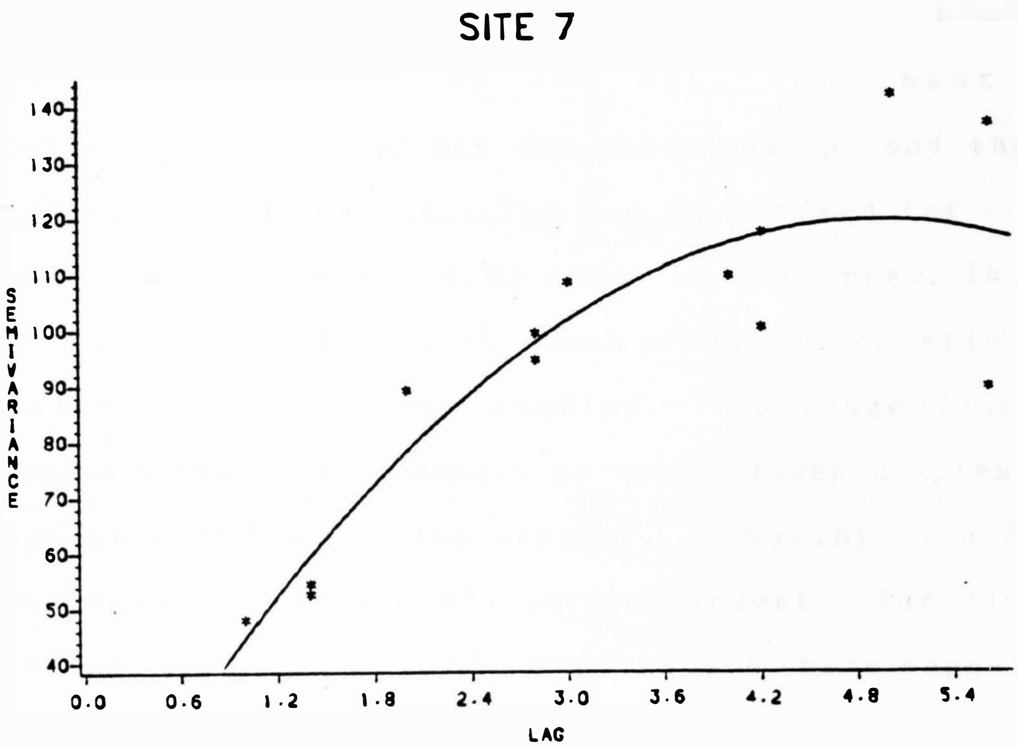
	range (meters)	sill	nugget effect
Linear	91.4	136.1	32.6
Quadratic	91.4	128.8	13.3



$$\gamma(h) = 32.6 + 20.7h$$

$$r^2 = 0.87$$

Figure 35. Linear semivariogram model for site 7.



$$\gamma(h) = 13.3 + 37.1h - 2.8h^2$$

$$r^2 = 0.89$$

Figure 36. Quadratic semivariogram model for site 7.

A summary of the models and parameters of the seven sites are given in tables 7 and 8. A spatial relationship between soil samples did exist for most sites. Semivariograms did detect the relationships and the ranges over which they existed. The ranges derived for each site are needed for determining sampling distances. The ranges indicated the distance at which a spatial relationship no longer existed between samples. The range denoted the minimum distance that should be used between samples to keep them independent of one another. Sampling at a distance less than the range would be inefficient. The range over the various sites varied from 0 meters (pure nugget effect for site 5) to 152.4 meters for Site 6.

No statistical comparisons between sites based on different tillage, fertilizer placements, and cropping sequences could be made. However, several interesting patterns did emerge.

There was a large difference between sites 5 and 6 even though both were treated the same as far as tillage, fertilizer placement, and cropping were concerned. Site 5 turned out to have a pure nugget effect indicating no spatial relationship between samples, and site 6 showed a spatial relationship with a range of 152.4 meters, the longest range of all sites. Sites 5 and 6 were only separated by several hundred meters, and a visual inspection

Table 7. Models for the seven sites.

site	model		r^2
1	linear:	$\gamma(h) = 52.9 + 11.9h$	0.75
1	quadratic:	$\gamma(h) = 21.2 + 35.3h - 3.4h^2$	0.87
2	linear:	$\gamma(h) = 36.9 + 3.7h$	0.58
2	quadratic:	$\gamma(h) = 20.6 + 18.5h - 2.8h^2$	0.84
3	linear:	$\gamma(h) = 7.5 + 1.0h$	0.44
3	quadratic:	$\gamma(h) = 5.4 + 3.1h - 0.4h^2$	0.51
		(approaching pure nugget effect)	
4	linear:	$\gamma(h) = 46.0 + 8.2h$	0.63
4	quadratic:	$\gamma(h) = 29.0 + 19.3h - 1.4h^2$	0.69
5		pure nugget effect	
6	linear:	$\gamma(h) = 9.5 + 20.4h$	0.73
6	quadratic:	$\gamma(h) = 38.9 + 5.9h - 1.3h^2$	0.75
7	linear:	$\gamma(h) = 32.6 + 20.7h$	0.87
7	quadratic:	$\gamma(h) = 13.3 + 37.1h - 2.8h^2$	0.89

Table 8. Parameters of the semivariogram models.

site	model	range (meters)	sill	nugget effect	(1) tillage	(2) fertilizer placement	(3) crop
1	lin.	91.4	124.3	52.9	R	Ba	CBR
1	quad.	79.2	112.8	21.2	R	Ba	CBR
2	lin.	64.0	52.4	36.9	R	Ba	CC
2	quad.	50.3	51.2	20.6	R	Ba	CC
3	lin.	61.0	11.5	7.5	C	Ba	CSGR
3	quad.	59.5	11.4	5.4	C	Ba	CSGR
4	lin.	106.7	103.4	46.0	R	Br	OCSR
4	quad.	105.1	95.5	29.0	R	Br	OCSR
5		pure nugget effect			R	Ba	CW
6	lin.	152.4	213.5	9.5	R	Ba	CW
6	quad.	152.4	227.9	38.9	R	Ba	CW
7	lin.	91.4	136.1	32.6	-	-	A
7	quad.	91.4	128.8	13.3	-	-	A

(1) R = reduced tillage
C = conventional tillage (moldboard plow)
(2) Ba = main fertilizer placement as bands
Br = main fertilizer placement by broadcast
(3) CBR = corn-barley rotation
CC = continous corn
CSGR = corn-small grain rotation
OCSR = oats-corn-soybean rotation
A = alfalfa

revealed no discernable differences in landscape appearance.

No explanation of this contrast is known at this time. Site 3, which was the only site moldboard plowed, also approached the pure nugget effect. Its range was the shortest except for the quadratic model of site 2 and site 5 (which did not have a range); and its sill and nugget effect were considerably lower than the other sites, indicating less variability in phosphorus levels across the field. A greater mixing of the soil through plowing leading to a homogenization of fertility levels throughout the field may explain the data of site 3. Also, site 3 had the lowest phosphorus average of all sites, and there is probably less variation associated with low average sites then with high average sites.

Sites that have a pure nugget effect appear to have a more uniform distribution of soil phosphorus than sites having semivariogram models. Sites with highly correlated semivariogram models seem to have moderately uniform areas (not points) of high, moderate, and low soil test values. These moderately uniform areas give the variability necessary to create a semivariogram model. Fields that show a nugget effect can have high, moderate, and low values also; but these values show up as points, not areas.

Another general trend that appeared was the correlation between site average and ranges (Table 9). The higher the site average, the longer its range. The

Table 9. Average phosphorus test values, standard deviation, and range for sites 1-7 (linear models only). Ranked according to the length of the ranges and the average phosphorus test values.

site	P ave. mg/kg	s.d.	range (meters)	range rank	ave. rank
1	17.5	13.3	91.4	3,4	4
2	14.5	8.1	64.0	5	6
3	10.6	6.4	61.0	6	7
4	20.3	10.2	106.7	2	2
5	18.9	11.6	-	7	3
6	26.3	20.1	152.4	1	1
7	16.3	12.7	91.4	3,4	5

exception to this was site 5 which had the third highest average but no range. Otherwise, the average rankings matched up closely with the length of range rankings. Larger homogenous areas exist within fields of high P averages and that those areas decrease in size with decreasing P averages. No explanation for this phenomenon exists at this time.

The range derived from a semivariogram can indicate the minimum sampling distance needed to give an unbiased estimation of the average fertility level of a field. The average value is really only worth while when the whole field is fairly uniform, but a strong semivariogram model indicates that the field is not uniform. Fertilizing based on the average, means that most of the field is either being under or over fertilized. This cannot be avoided, but it should be minimized if possible. Accurate fertilization depends on knowing where the moderately uniform areas exist.

The semivariogram model in itself does not aid in finding the uniform areas are; it only indicates that they exist. The very act of gathering samples to create a semivariogram would also give that information, but very few people are willing to spend the time and money necessary to collect the data needed. The problem therefore becomes how to discover those uniform areas of variable fertility levels at minimum expense. Those areas sampled should not be smaller than what a farmer would be willing to treat differently by adjusting his fertilizer rate. It does no good to determine the variability of a field if it is all going to be treated the same anyhow. The method of creating a semivariogram somewhat lends itself to partially solving the field variability problem at minimum expense.

First a normal sampling procedure will be compared to a proposal for a new sampling scheme. Figure 37 represents a 25 hectare field that has been in continuous wheat.

A normal sampling procedure would probably consist of collecting four composite samples as labeled in Figure 37. This procedure may give a good indication of fertility variability in the field, but it probably will not lend itself to different fertilizer application rates.

On the other hand, if the same field could be divided into three horizontal strips and three composite samples gathered, followed by dividing it into three vertical strips and three more composite samples gathered, (Figure 38) the pattern of field variability may become discernible.

Next, the variabilty of the three horizontal composite samples will be compared to the variability of the three vertical composite samples. The most variable of the two is then chosen as the basis for fertilizer recommendations for that field, with individual recommendations made for each

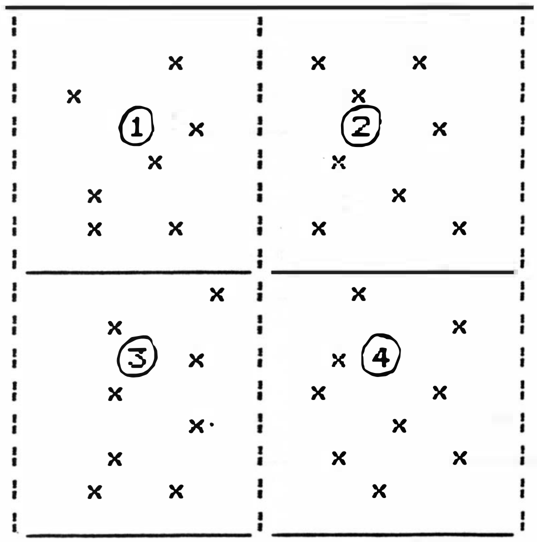


Figure 37. Four composite samples gathered by mixing the soil collected at each x. The circled numbers represent the composite samples.

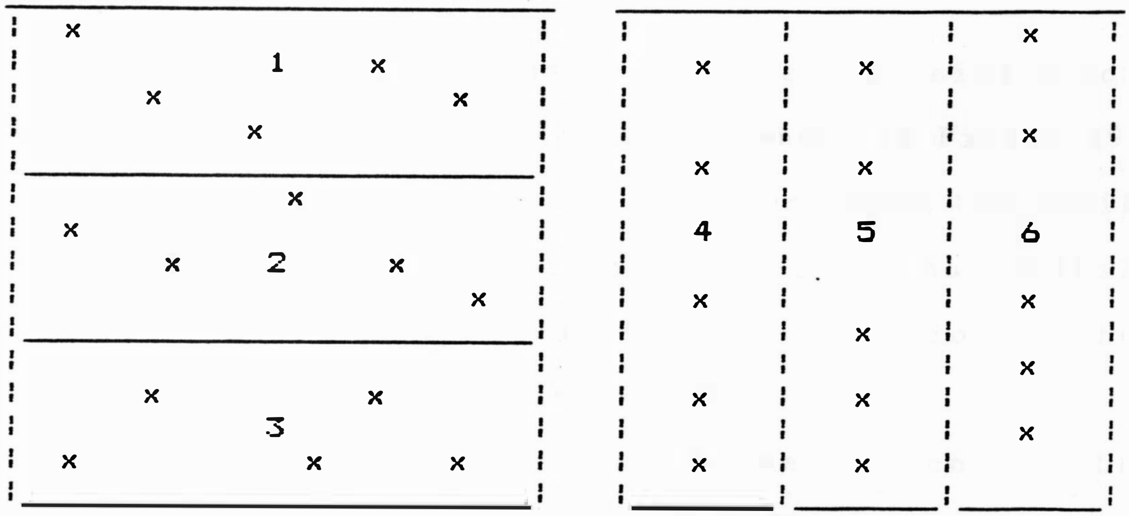


Figure 38. Composite samples taken from horizontal and vertical strips of the field.

strip. Each strip should be large enough so as to be treated as a separate unit.

The average phosphorus test values for site 5 for each horizontal and vertical strip are shown in Figure 39. The transformed values were used in determining the strip averages. The standard deviation of the three horizontal composite samples = 1.65. The standard deviation of the three vertical composite samples = 1.29.

Earlier, the site 5 samples were found to be spatially independent. The similarity of the average values of the horizontal and vertical strips seem to indicate a relatively uniform distribution of values across the field. The standard deviations of the three composite samples both horizontally (1.65) and vertically (1.29) are low. Because of the similarity between the composite samples within each direction and between directions, a single rate of fertilization can be applied to the entire field.

The average phosphorus test values for site 6 for each horizontal and vertical strip are shown in Figure 40. The transformed values were used in determining the strip averages. The standard deviation of the three horizontal composite samples = 10.36. The standard deviation of the three vertical composite samples = 7.16.

Site 6 samples were found to be spatially dependent up to 152.4 meters. The three average values of the horizontal

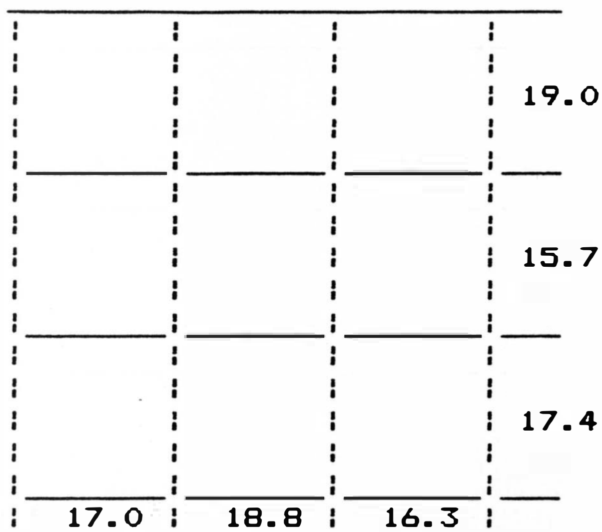


Figure 39. Average phosphorus test values (mg P/kg soil) for the 3 horizontal and vertical strips for site 5.

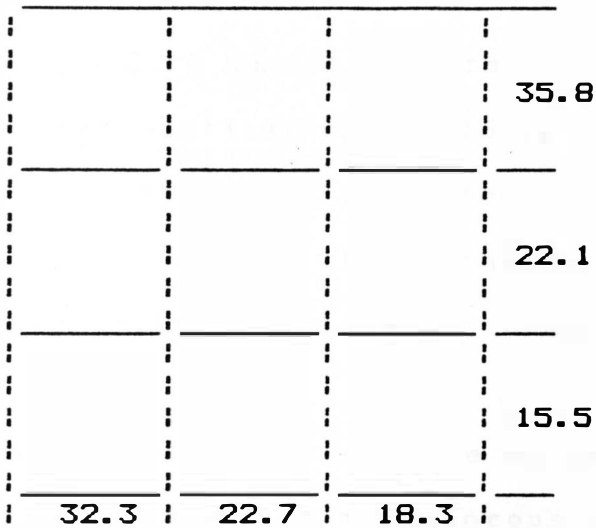


Figure 40. Average phosphorus test values (mg P/kg soil) for the 3 horizontal and vertical strips of site 6.

and vertical strips seem to indicate an uneven distribution of values across the field. The standard deviation of the three composite samples taken from the horizontal strips is larger than the standard deviation form the vertical strips. Therefore fertilizer application should be on the horizontal strips, with each strip receiving differing rates. Over and under fertilization would still be taking place, but at a reduced rate with strip fertilization compared to applying just one rate.

Site 7 is also a good example of the advantage of strip sampling. The average phosphorous test values for site 7 are shown in Figure 41. Site 7 was a 14 by 14 grid, the top four rows of samples went into the top composite horizontal sample and five rows each in the other two. Four columns went into the left vertical stip composite sample and five columns each in the other two. The standard deviation of the three horizontal composite samples = 10.68, and the standard deviation of the three vertical composite samples = 0.93. There is little difference between the vertical composite samples, but a 20 mg/kg difference exists between the top and bottom horizontal stips. Fertilizing the horizontal strips accordingly would reduce over and under fertilization.

			29.4
			12.9
			9.4
16.8	17.0	15.3	

Figure 41. Average phosphorus soil test values (mg P/kg soil) for the 3 horizontal and vertical strips for site 7.

SUMMARY AND CONCLUSIONS

Field spatial variability appears to be the weakest link in the fertilizer recommendation program. Soil variation has increased due to the additions of fertilizers, and sampling systems once adequate for unfertilized fields are probably inadequate for heavily fertilized fields (Melsted, 1967). Variations of soil test results are not always errors in sampling but may be a true representation of the field's fertility pattern (Melsted, 1967). Fertilizer application based on average soil test values is of questionable value since much of the field will be over or under fertilized, especially if large variations exist in the field (Peck and Melsted, 1967). A good sampling scheme should depict the level and extent of nutrient deficiency patterns within a field with only a few composite samples (Cameron et al., 1971). Once the fertility pattern of a field is known, appropriate fertilizer rates can be applied to different parts of the field to smooth out the variation (James and Dow, 1972).

This study showed spatial relationships, as determined by semivariograms, existed between soil phosphorus samples in five sites, was questionable in one site, and did not exist in one site. The distance in which samples were related ranged from 61.0 meters to 152.4 meters. The impact of these spatial relationships on commercial agriculture is slight since most soil samples are

REFERENCES CITED

Ball, D. F. and W. M. Williams. 1968. Variability of soil chemical properties in two uncultivated brown earths. J. Soil. Sci. 19:379-391.

Bartlett, R. and B. James. 1980. Studying dried, stored soil samples-some pitfalls. Soil Sci. Soc. Am. J. 44:721-724.

Beckett, P. H. T. and R. Webster. 1971. Soil variability: a review. Soils and Fertilizers. 34:1-15.

Burgess, T. M. and R. Webster. 1980a. Optimal interpolation and isarithmic mapping of soil properties. I. The semivariogram and punctual kriging. J. Soil Sci. 31:315-331.

Burgess, T. M. and R. Webster. 1980b. Optimal interpolation and isarithmetic mapping of soil properties. III. Changing drift and universal kriging. J. Soil Sci. 31:505-524.

Cameron, D. R., M. Nyborg, J. A. Toogood, and D. H. Laverty. 1971. Accuracy of field sampling for soil tests. Can. J. Soil Sci. 51:165-175.

Cline, M. G. 1944. Principles of soil sampling. Soil Sci. 58:275-288.

Collins, J. B., E. P. Whiteside, and C. E. Cress. 1970. Seasonal variability of pH and lime requirements in several southern Michigan soils when measured in different ways. Soil Sci. Soc. Am. Proc. 34:56-61.

Crocker, R. L. 1960. The plant factor in soil formation. Proc. Ninth Pacific Science Congress. 18:84-90.

David, M. 1977. Developments in geomathematics 2. Geostatistical ore reserve estimation. Elsevier Scientific Publ. Co., 364 p.

Davis, J. C. 1973. Statistics and data analysis in geology. John Wiley and Sons Inc., New York. 550 p.

Donahue, R. L., R. W. Miller, and J. C. Shickluna. 1983. Soils: an introduction to soils and plant growth. Prentice-Hall, Englewood Cliffs, New Jersey, 667 p.

Eik, K., E. L. Hood, and J. J. Hanway. 1975. Soil sample preparation. In NC Regional Pub. No. 221, N. Dak.

Agric. Exp. Sta. Bull. 499, Fargo, N.D. p. 2-3.

Ferrari, Th. J. and F. H. B. Vermeulen. 1955. Soil heterogeneity and soil testing. Neth. J. Agric. Sci. 3:265-275.

Gallagher, P. A. and M. Herlihy. 1963. An evaluation of errors associated with soil testing. Irish J. Agric. Res. 2:149-167.

Grava, J., G. E. Spalding, and A. C. Caldwell. 1961. Effect of drying upon the amounts of easily extractable potassium and phosphorus in Nicollet clay loam. Agron. J. 53:219-221.

Hammond, L. C., W. L. Pritchett, and V. Chew. 1958. Soil sampling in relation to soil heterogeneity, Soil Sci. Soc. Am. Proc. 22:548-552.

Harradine, F. F. 1949. The variability of soil properties in relation to stage of profile development. Soil Sci. Soc. Am. Proc. 14:302-311.

Hemingway, R. G. 1955. Soil sampling errors and advisory analyses. J. Ag. Sci. 46:1-7.

Horton, H. A., F. A. Stinson 1939. Investigations in sampling soils previously fertilized for flue-cured tobacco. Sci. Agric. 19:616-621.

Hulbert, W. C. and R. G. Menzel. 1953. Soil mixing characteristics of tillage implements. Ag. Eng. 34:702-708.

Ike, A. F. and J. L. Clutter. 1968. The variability of forest soils of the Georgia Blue Ridge Mountains. Soil Sci. Soc. Am. Proc. 32:284-288.

James, D. W. and A. I. Dow. 1972. Source and degree of soil variation in the field: The problem of sampling for soil tests and estimating soil fertility status. Wash. Agr. Exp. Sta. Bull. 749.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Co., New York, 281 p.

Jenny, H. 1958. Role of the plant factor in the pedogenic functions. Ecology. 39:5-16.

Leo, M. W. M. 1963. Heterogeneity of soil of agricultural land in relation to soil sampling. J. Ag. Food Chem.

11:432-434

Luebs, R. E., G. Stanford, and A. D. Scott. 1956. Relation of available potassium to soil moisture. Soil Sci. Soc. Proc. 20:45-50.

MacLean, A. J. and R. Summerby. 1945. A Study of the variability of certain chemical properties in soils. Sci. Am. 25:221-228.

Malo, D. D. and B. K. Worcester. 1975. Soil fertility and crop responses at selected landscape positions. Agron. J. 67:397-401.

Matheron, G. 1963. Principles of geostatistics. Economic Geology 58:1246-1266.

McIntyre, G. A. 1967. Soil sampling for soil testing. Aust. Inst. Agric. Sci. J. 33:309-320.

Melstead, S. W. 1967. The philosophy of soil testing. In Soil Testing and Plant Analysis, Paty I. Soil Soc. Am., Inc., Madison, Wisc.

Mountier, N. S. and C. During. 1967. Sources of error in advisory soil tests. IV. Discussion of total variance. N.Z. J. Agric. Res. 10:134-138.

Mountier, N. S., J. L. Grigg, and G. A. C. Oomen. 1966. Sources of error in advisory soil tests. I. Laboratory sources. N.Z. J. Agric. Res. 9:328-338.

Opio, T. K. 1971. An evaluation of variation in soil test results caused by sampling methods and individual samplers. M.S. Thesis. South Dakota State Univ., Brookings, S.D.

Peck, T. R. and S. W. Melstead. 1967. Field sampling for soil testing. In Soil Testing and Plant Analysis, Part I. Soil Sci. Soc. Am. Inc., Madison, Wisc.

Post, A. H. 1924. Soil variability as determined by statistical methods. Soil Sci. 17:343-357.

Raupach, M. 1951. Studies in the variation of soil reaction. Aust. J. Agric. Res. 2:83-91.

Reed, J. F. and J. A. Rigney. 1947. Soil sampling from fields of uniform and nonuniform appearance and soil types. J. Am. Soc. Agron. 39:26-40.

Soil Testing Procedures. 1980. South Dakota State Univ. Agric. Expt. Sta., Brookings, S.D. Pamphlett No. 55.

Spratt, E. D. and R. N. McIver. 1972. Effects of topographical positions, soil test values, and fertilizer use on yields of wheat in a complex of black chernozemic and gleysolic soils. Can. J. Soil Sci. 52:53-58.

Tisdale, S. L. and W. L. Nelson. 1975. Soil fertility and fertilizers. Macmillan Publ. Co., Inc., 694p.

Towner, G. D. 1968. Variability of soil moisture in the black cracking clay soil of north-western New South Wales. Aust. J. Exp. Agric. Anim. Husb. 8:252-254.

Ulrich, R. 1949. Some physical changes accompanying Prarie, Wiesenboden and Planosol soil profile development from Peoria loess in southwestern Iowa. Soil Sci. Soc. Proc. 14:287-295.

Vieira, S. R. 1982. Geostatistical analysis of some agronomical observations. Ph. D. Dissertation. Univ. Ca.-Davis.

Welch, C. D. and J. W. Fitts. 1956. Some factors affecting soil sampling. Soil Sci. Soc. Proc. 20:54-56.

Westfall, D. G., M. A. Henson, and E.P. Evans. 1978. The effect of soil sample handling between collection and drying on nitrate concertration. Comm. in Soil Sci. and Plant Analysis. 9:169-175.

Westin, F. C. 1978. Organic phosphorus changes over a growing season in some Borolls and associated Aquoll of South Dakota. Soil Sci. Soc. Am. J. 42:472-477.

Young, A. 1973. Soil survey procedures in land development planning. Geographical J. 139:53-64.

APPENDIX

Table A-1

Site locations:

Kingsbury county sites:

Site 1 was located in the NE1/4 of Sec. 12, T. 111 N., R. 55W. It belonged to Wayne Odegaard and is located approximately 8.1 km north and 0.3 km west of Lake Preston, S.D.

Site 2 was located in the NE1/4 of Sec. 12, T. 111 N., R. 55W. It also belonged to Wayne Odegaard and is located approximately 8.1 km north and 0.6 km west of Lake Preston.

Site 3 was located in the SE1/4 of Sec. 1, T. 111 N., R. 55W. It belonged to Allan Rieck and is located approximately 8.4 km north and 0.6 km west of Lake Preston.

Site 4 was located in the SE1/4 of Sec. 11, T. 111 N., R. 55W. It is located approximately 7.9 km north and 1.6 km west of Lake Preston.

Brown county sites:

Site 5 was located in the SW1/4 of Sec. 19, T. 124 N., R. 62W. It belonged to Arly Hansen and was located approximately 8.1 km north and 0.4 km west of Bath, S.D. on the north side of the road.

Site 6 was located in the NW1/4 of Sec. 30, T. 124 N., R. 62 W. It also belonged to Arly Hansen and was located at the same place as site 5 but on the south side of the road.

Brookings county site:

Site 7 was located in the NW1/4 of Sec. 35,T. 111 N., R. 49W. Itwaslocated approximately 6.4km north of Brookings on highway 77 and 8.4 km east.

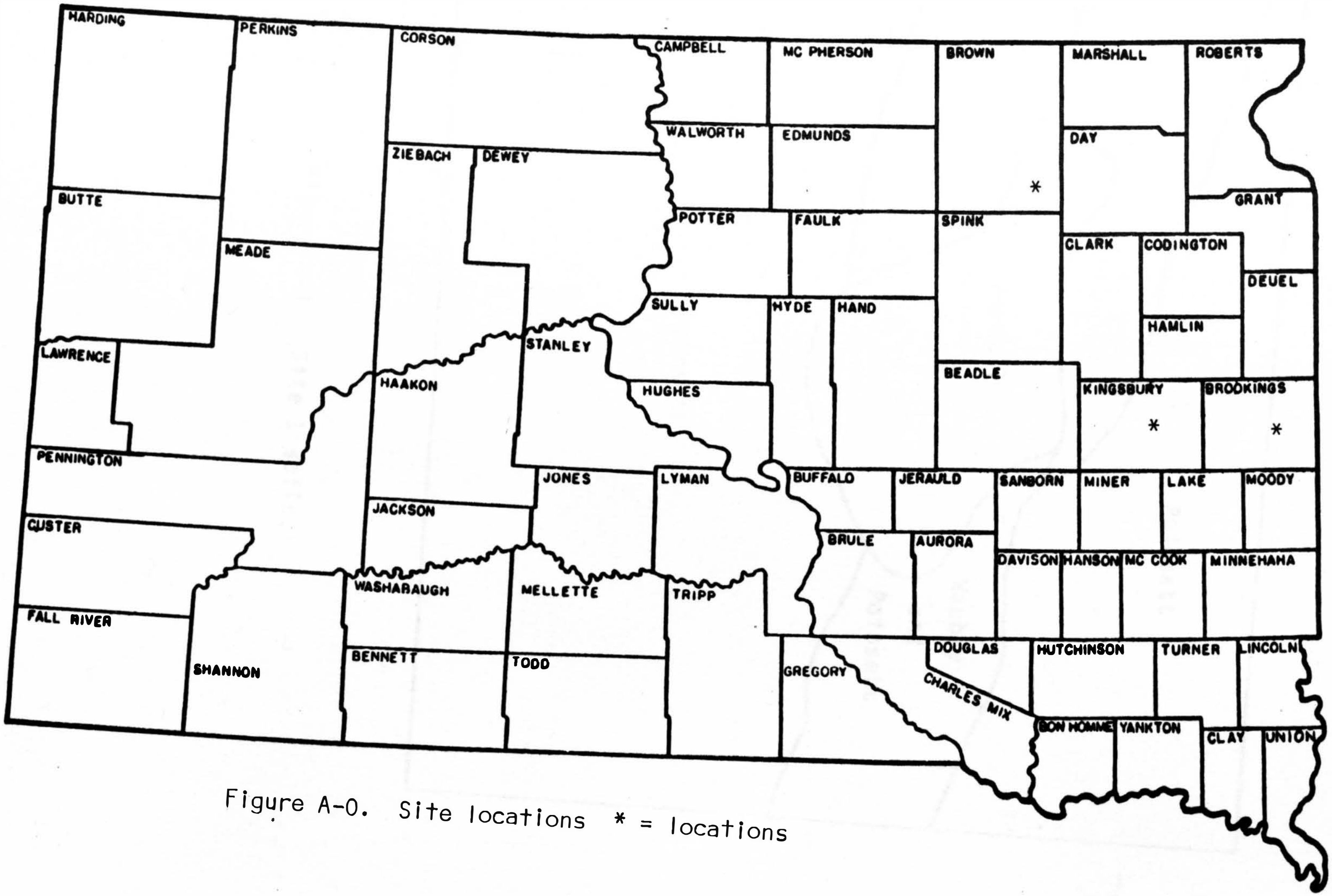


Figure A-0. Site locations * = locations

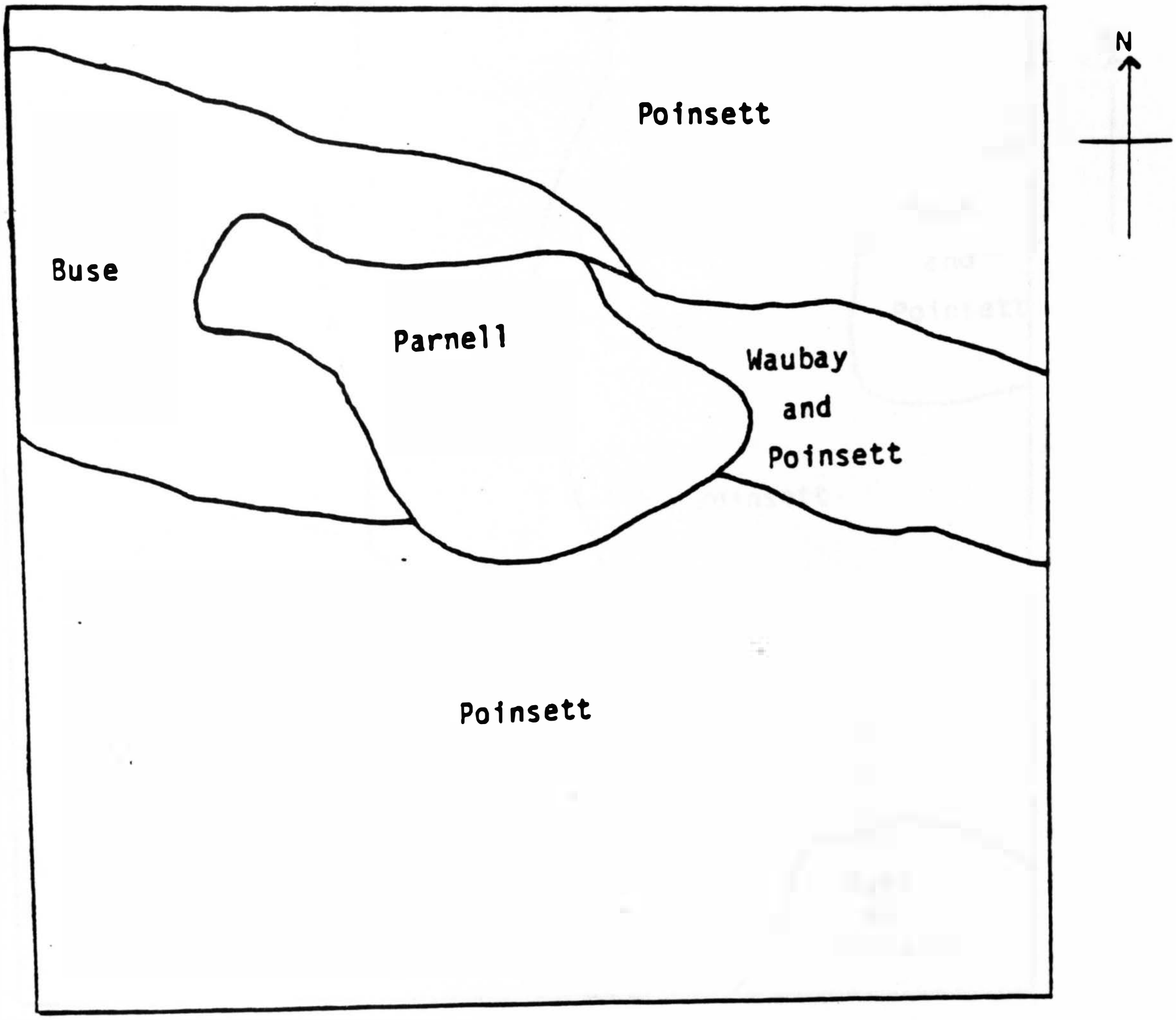


Figure A-1. Site 1 soils.

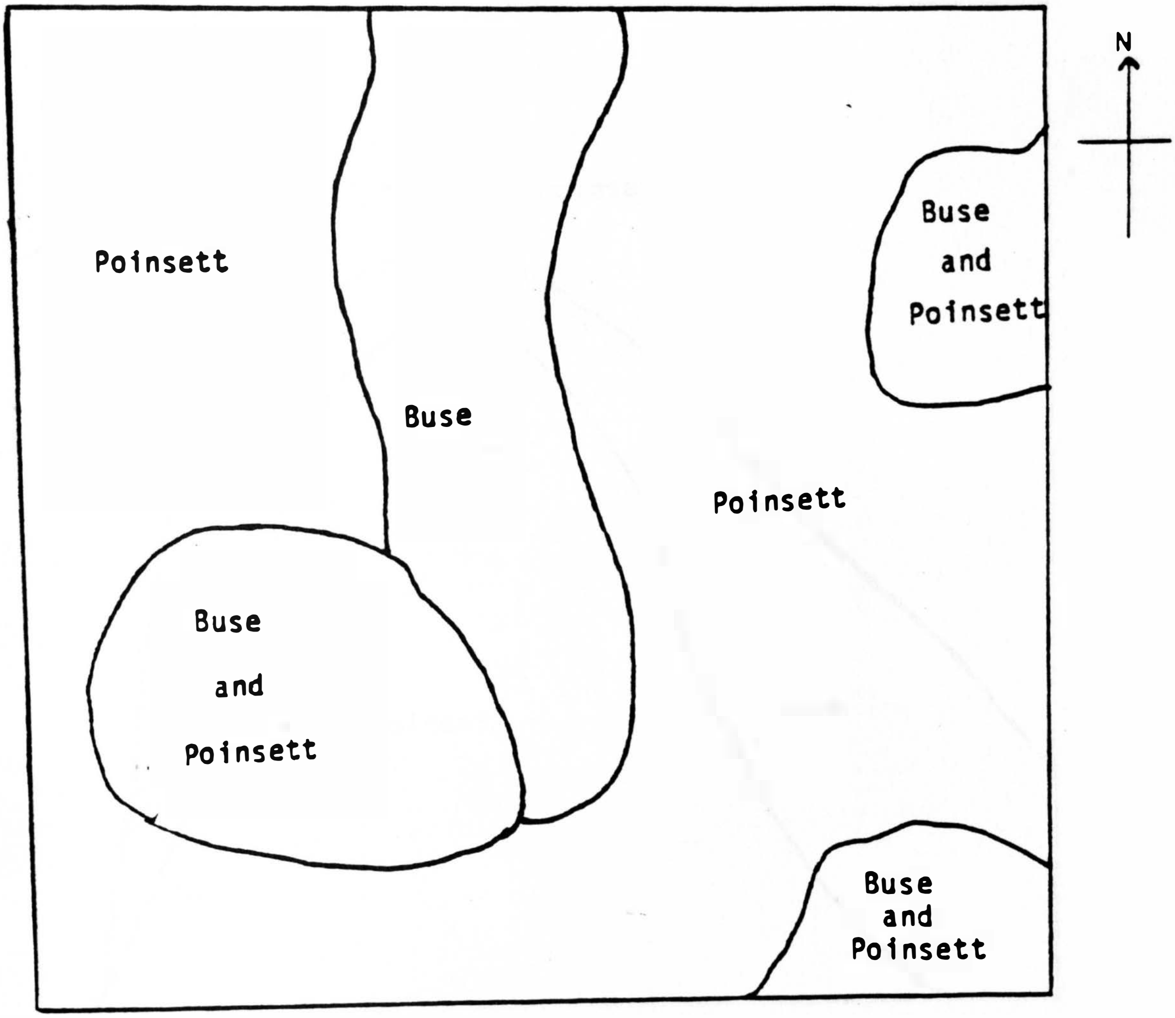


Figure A-2. Site 2 soils.

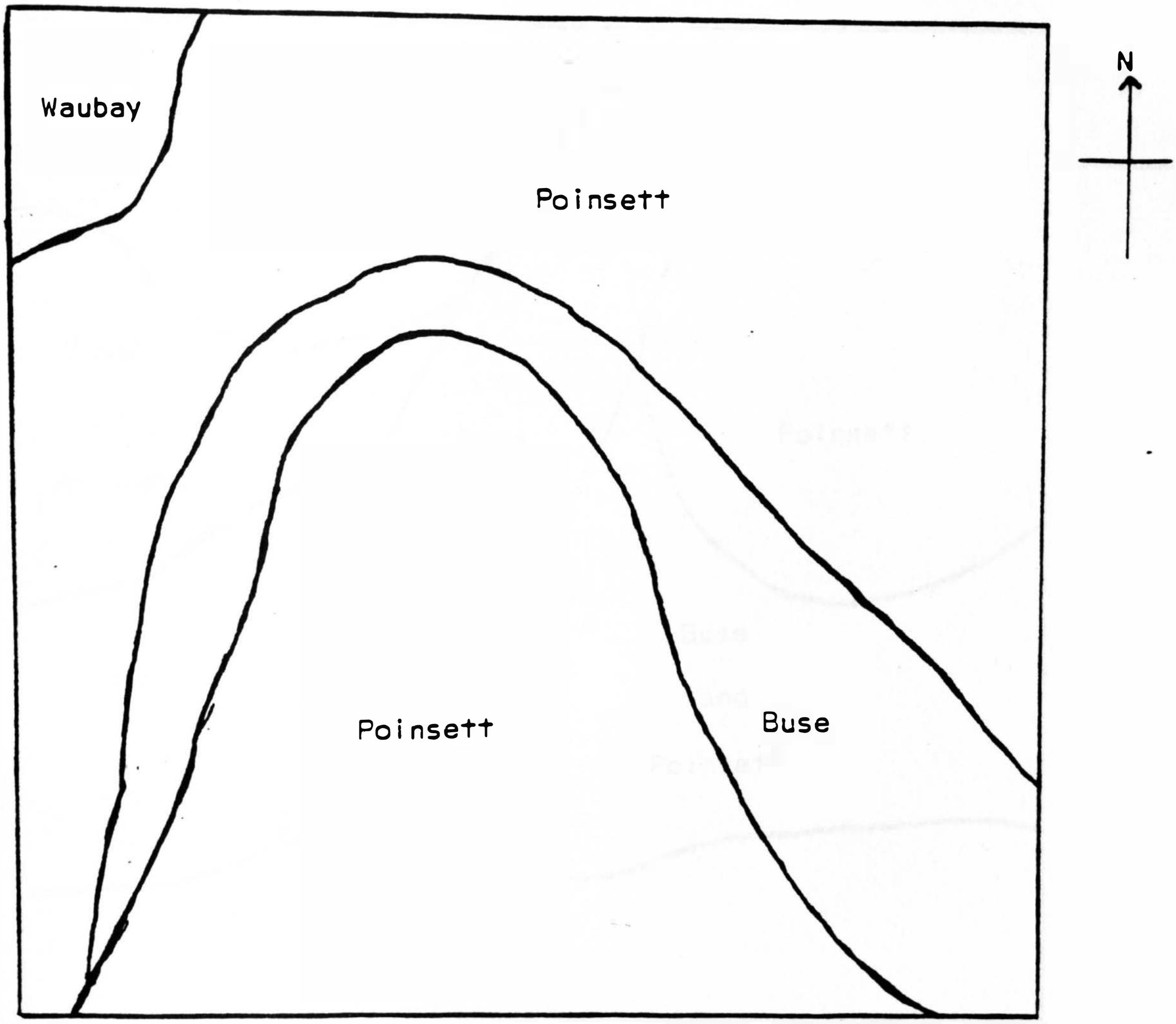


Figure A-3. Site 3 soils.

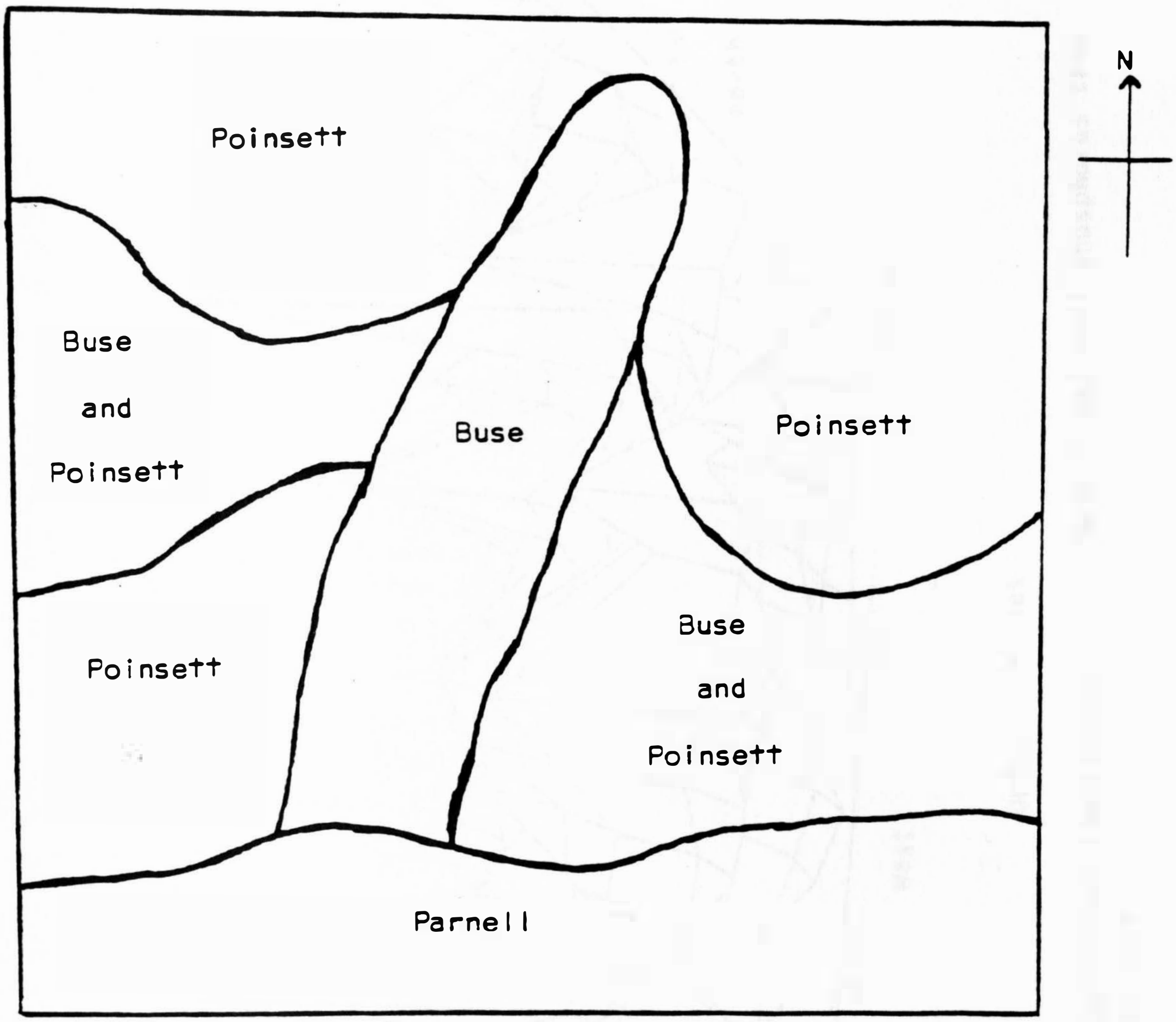
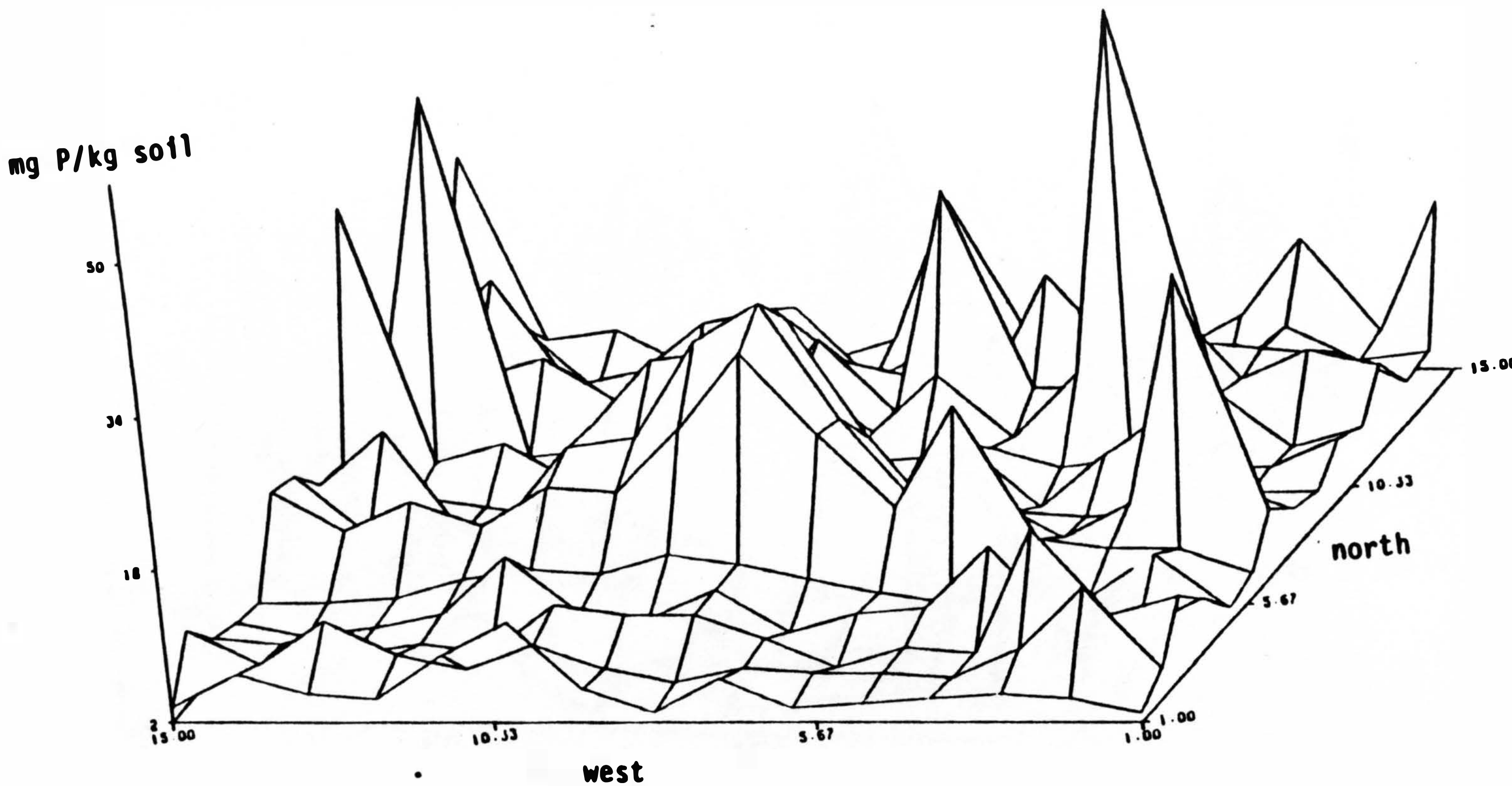
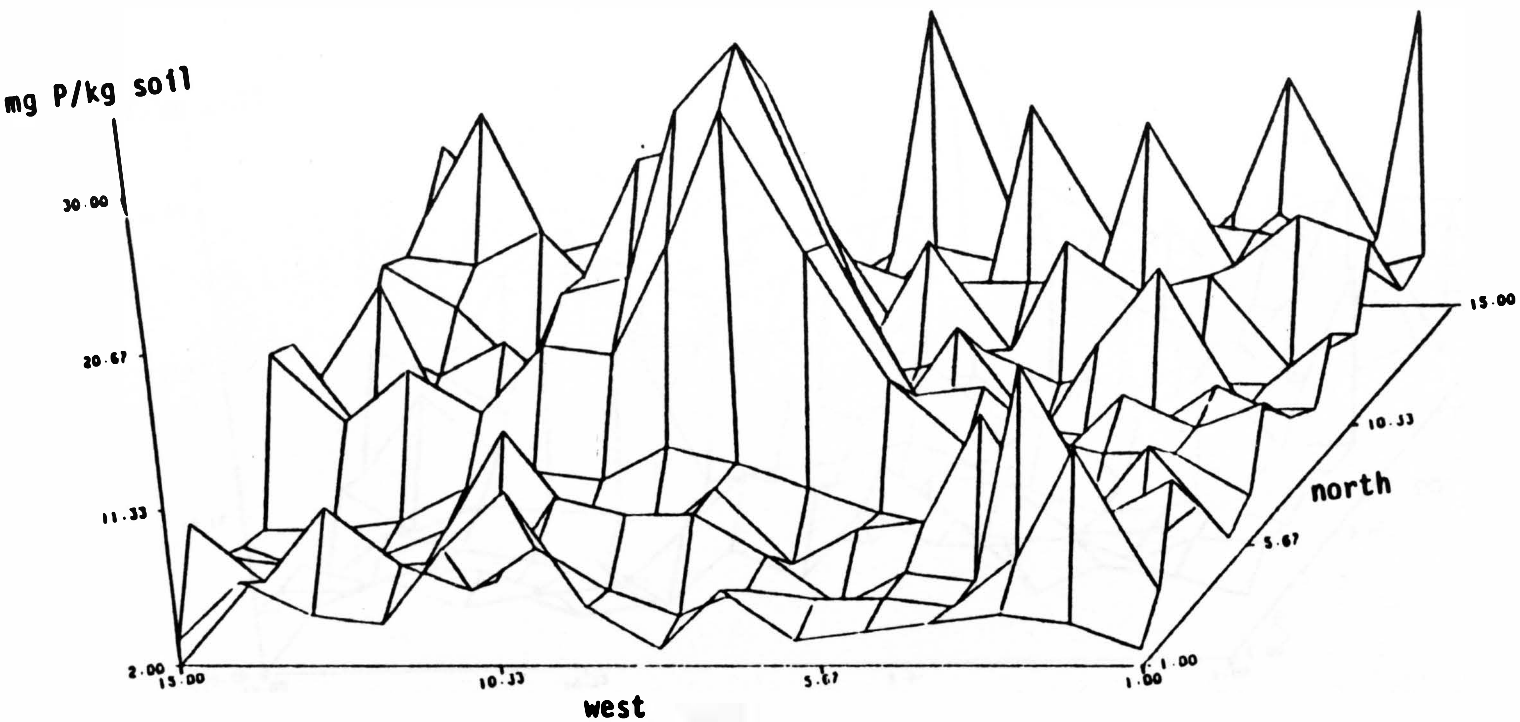


Figure A-4. Site 4 soils.



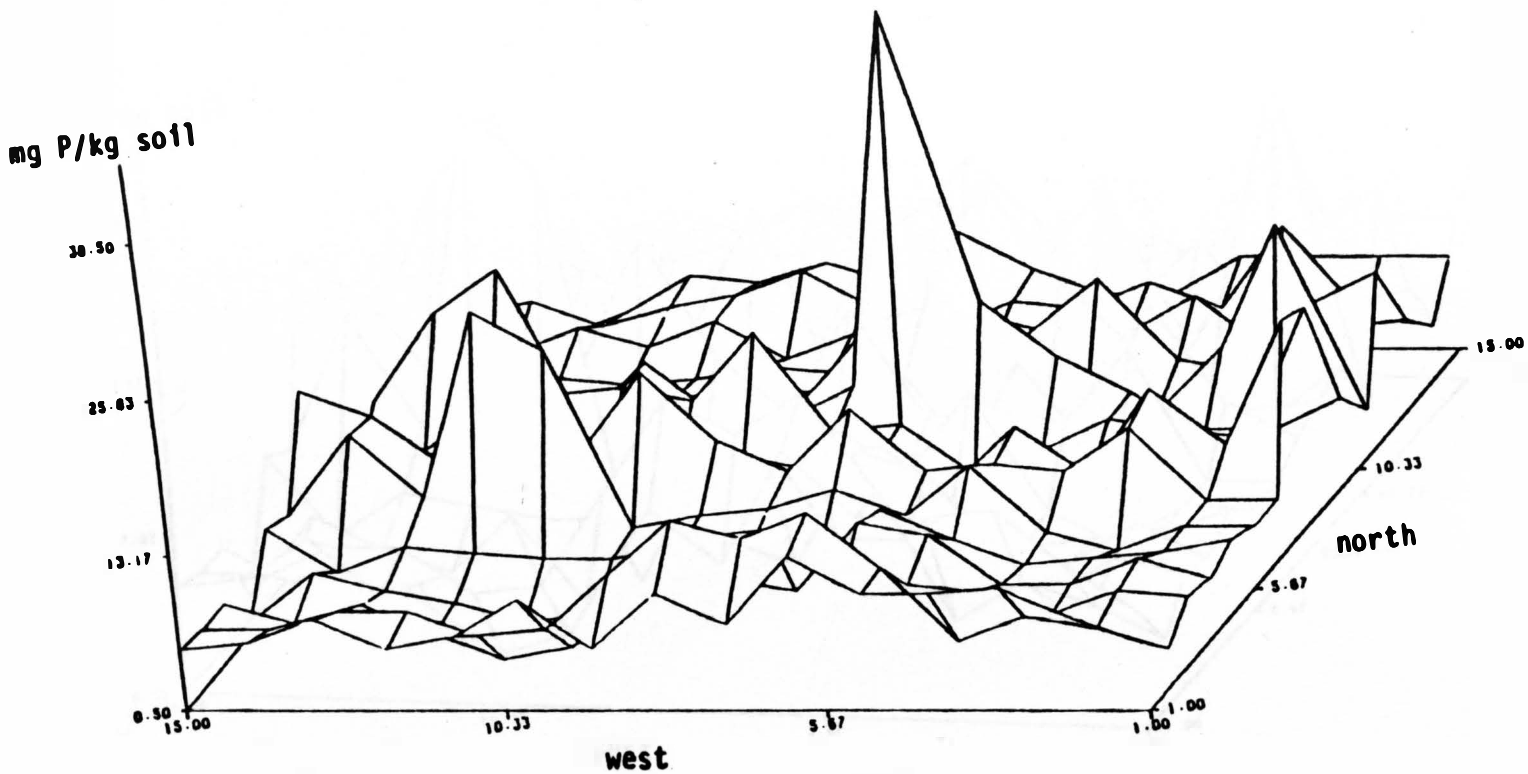
Original Values

Figure B-1. Three dimensional representation of the original soil phosphorus test values of site 1.



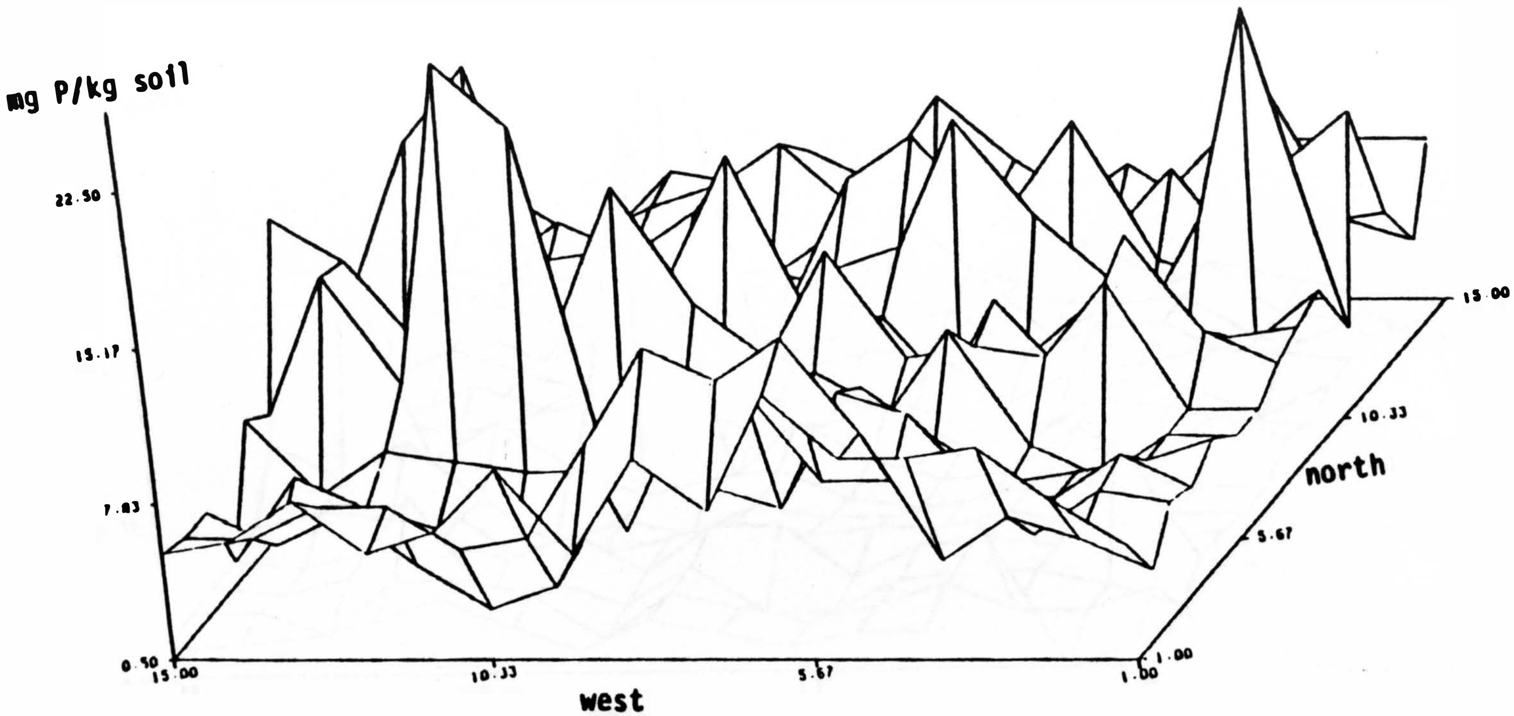
Transformed Values

Figure B-2. Three dimensional representation of the transformed soil phosphorus test values of site 1.



Original Values

Figure B-3. Three dimensional representation of the original soil phosphorus test values of site 2.



Transformed Values

Figure B-4. Three dimensional representation of the transformed soil phosphorus test values of site 2.

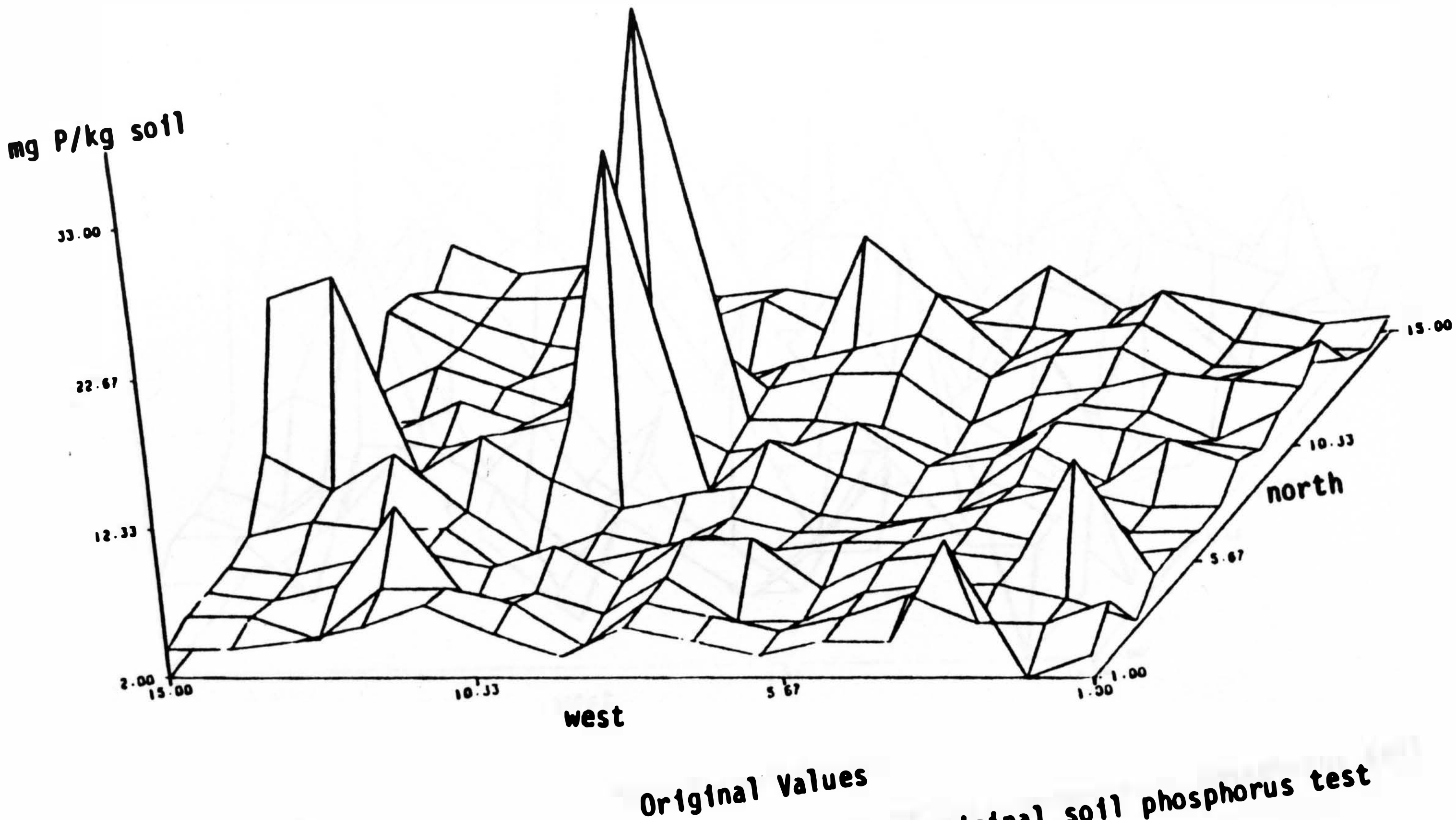
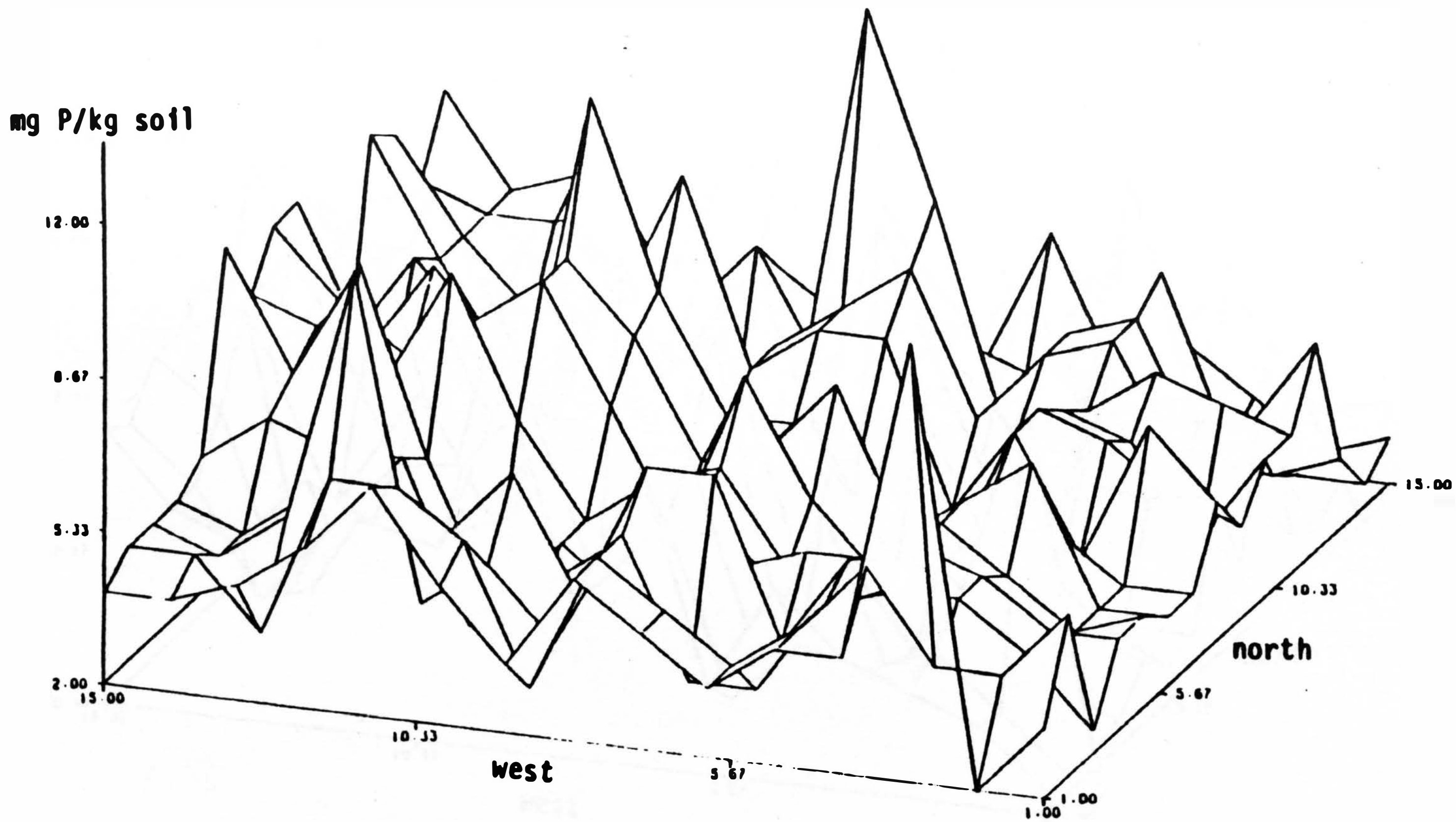
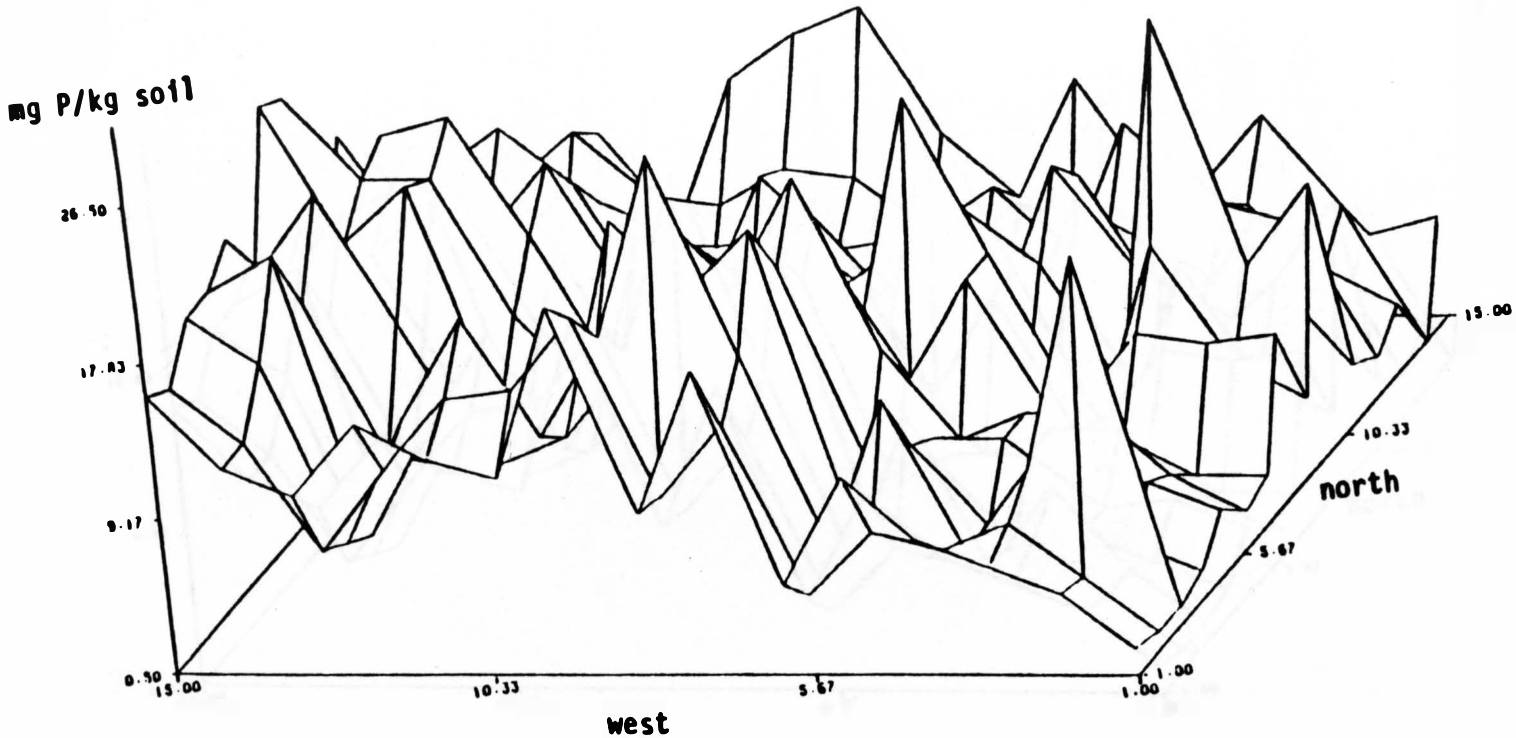


Figure B-5. Three dimensional representation of the original soil phosphorus test values of site 3.



Transformed Values

Figure B-6. Three dimensional representation of the transformed soil phosphorus test values of site 3.



Original Values

Figure B-7. Three dimensional representation of the original soil phosphorus test values of site 4.

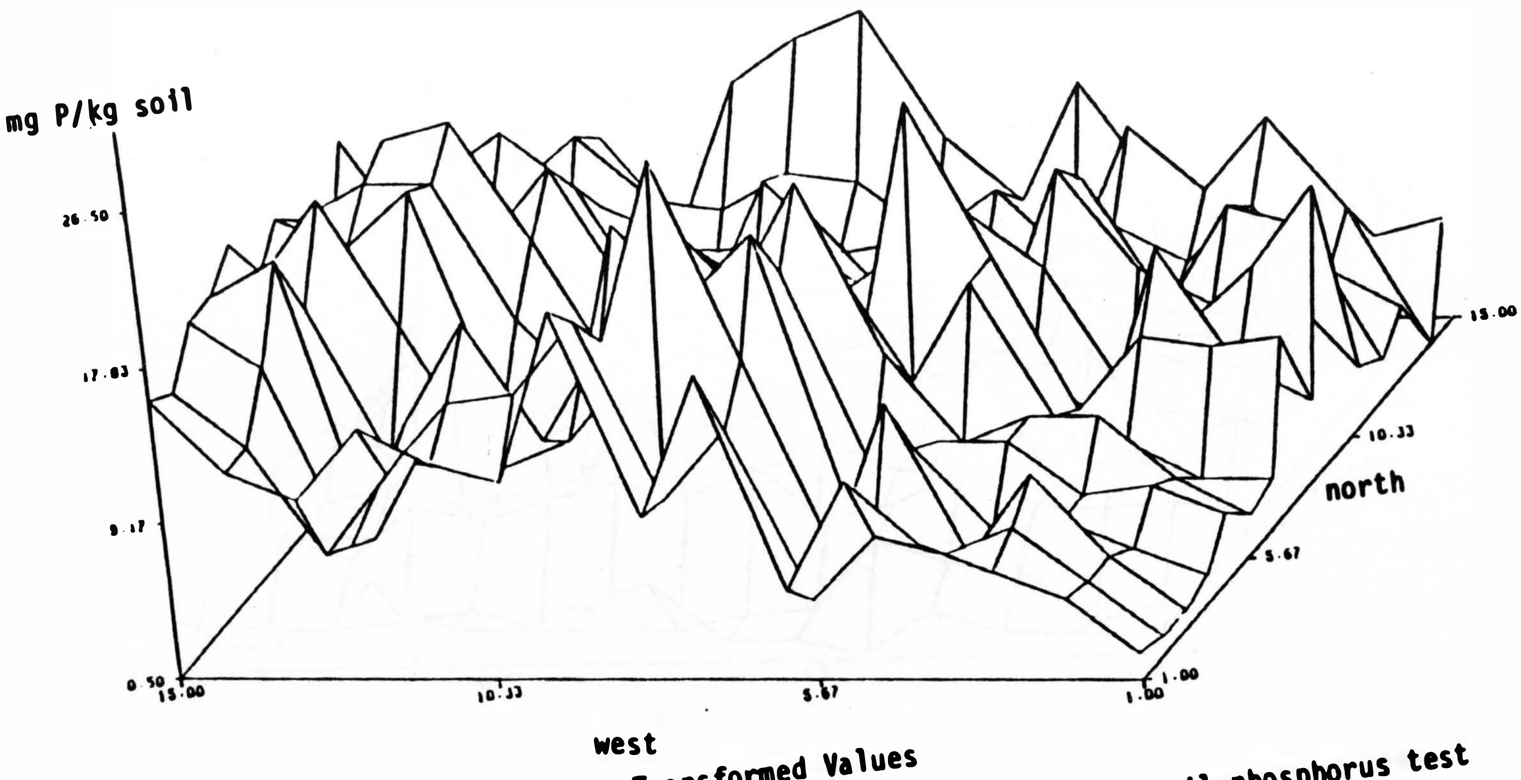
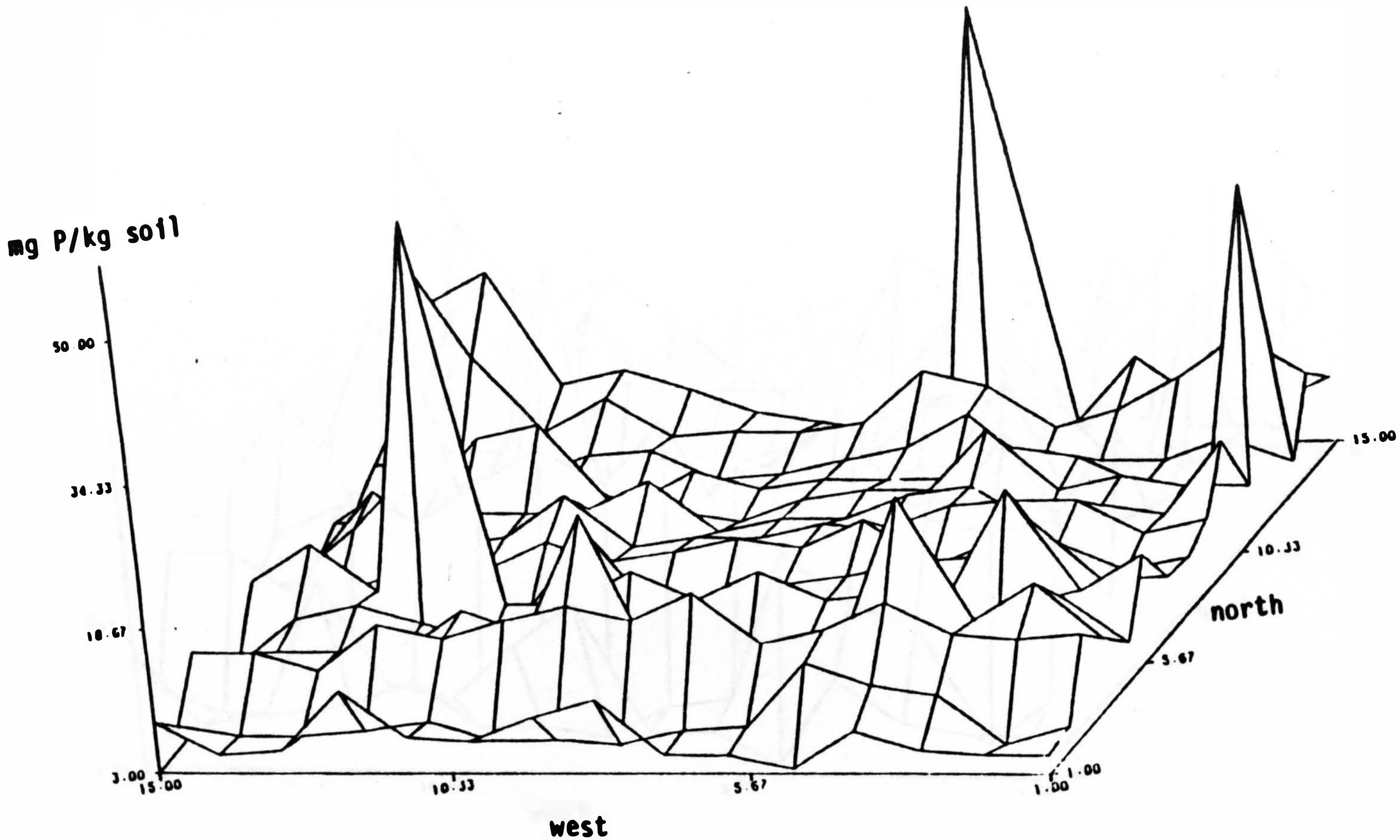
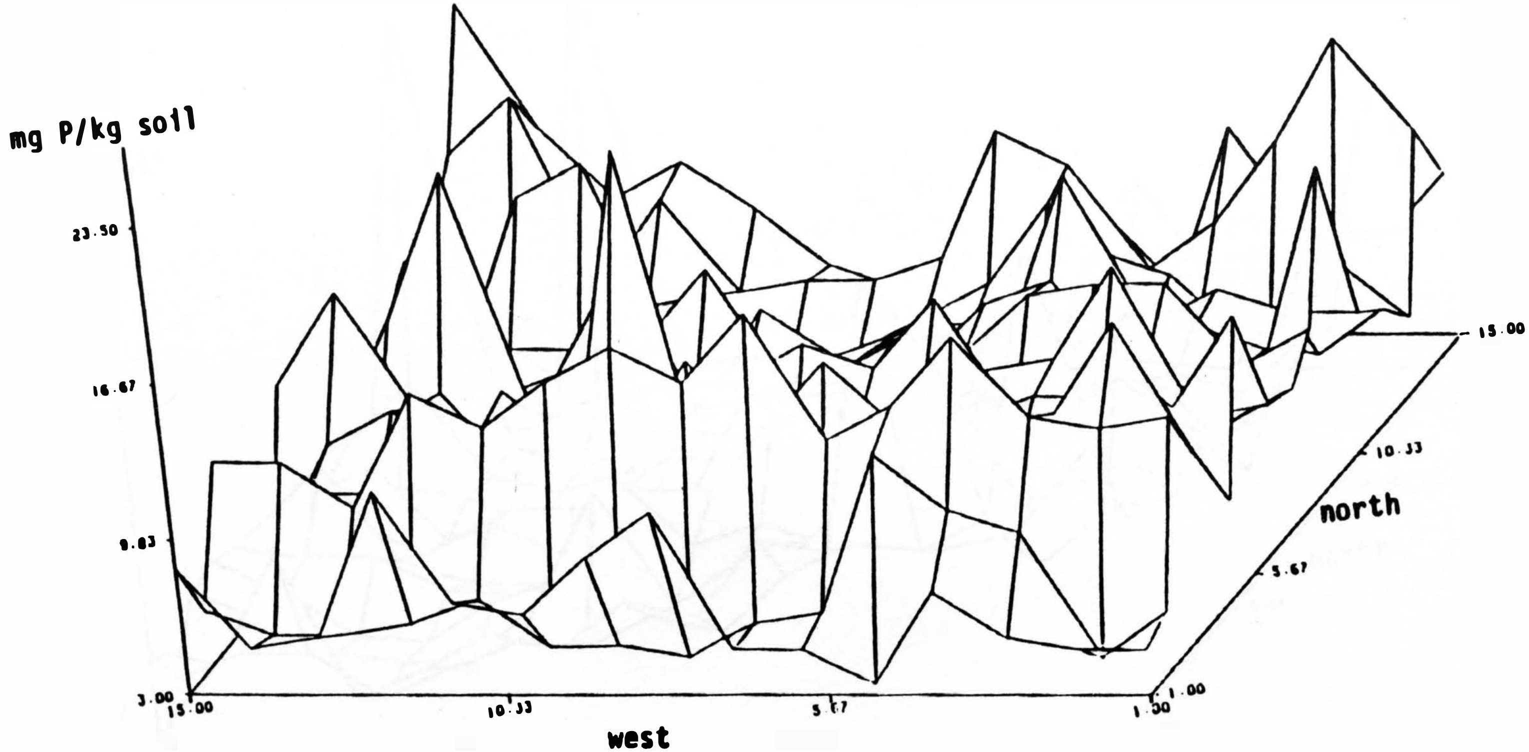


Figure B-8. Three dimensional representation of the transformed soil phosphorus test values of site 4.



Original Values

Figure B-9. Three dimensional representation of the original soil phosphorus test values of site 5.



Transformed Values

Figure B-10. Three dimensional representation of the transformed soil phosphorus test values of site 5.

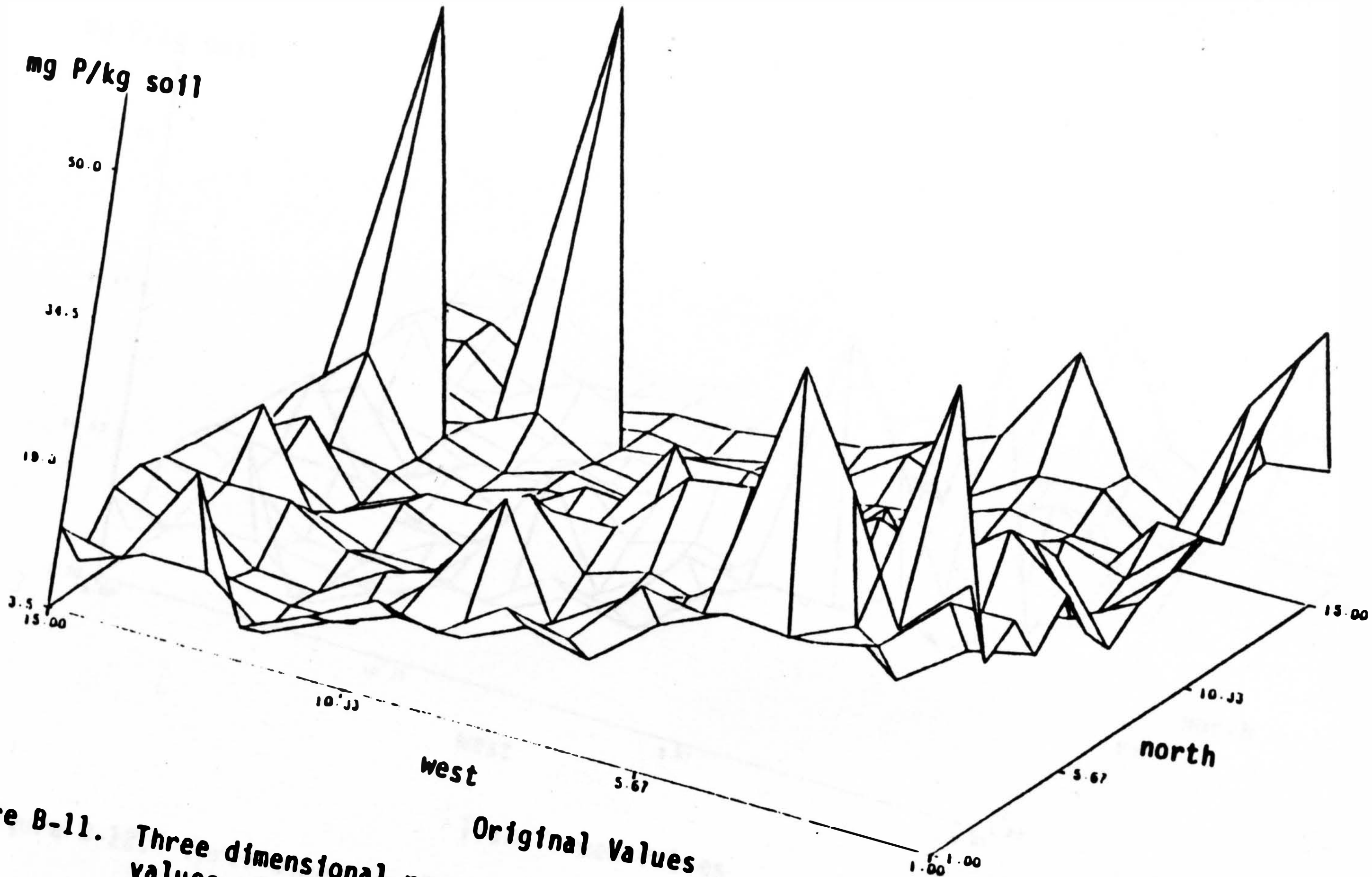
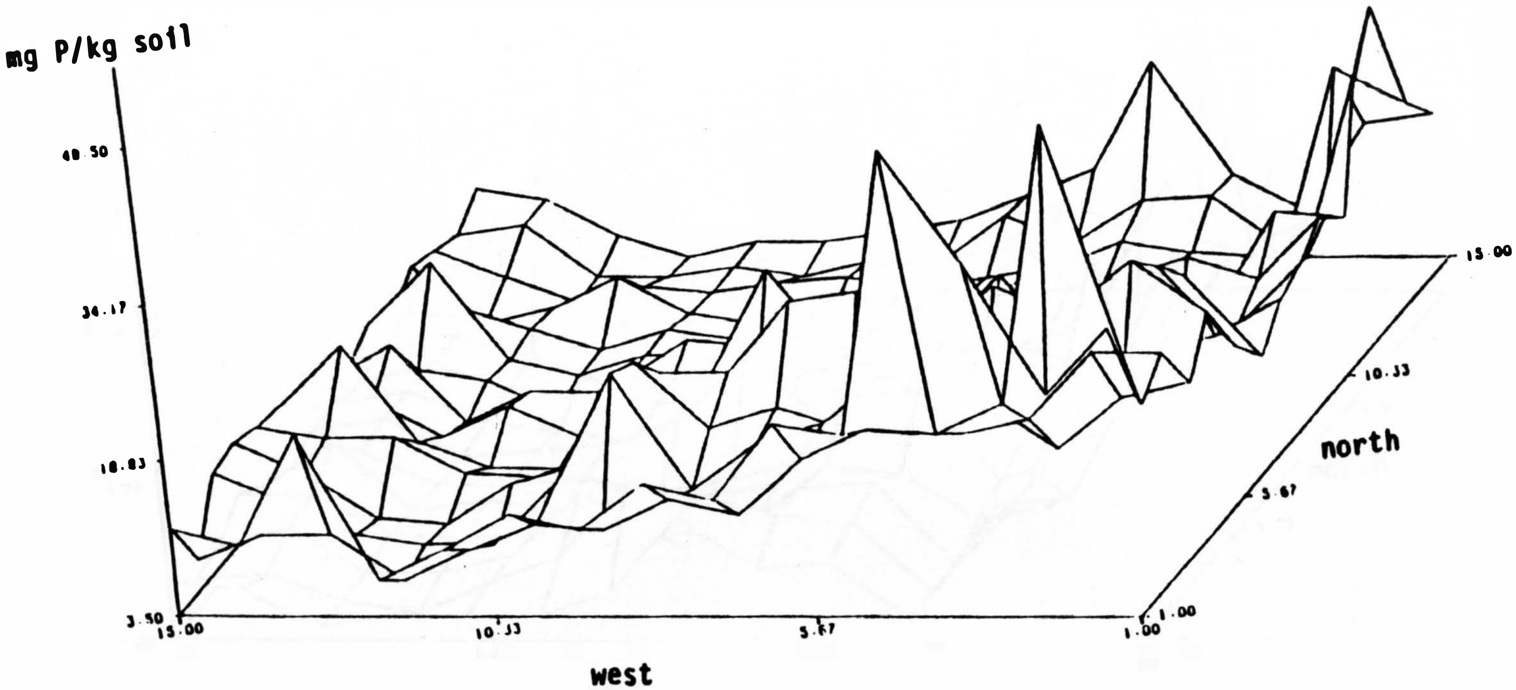
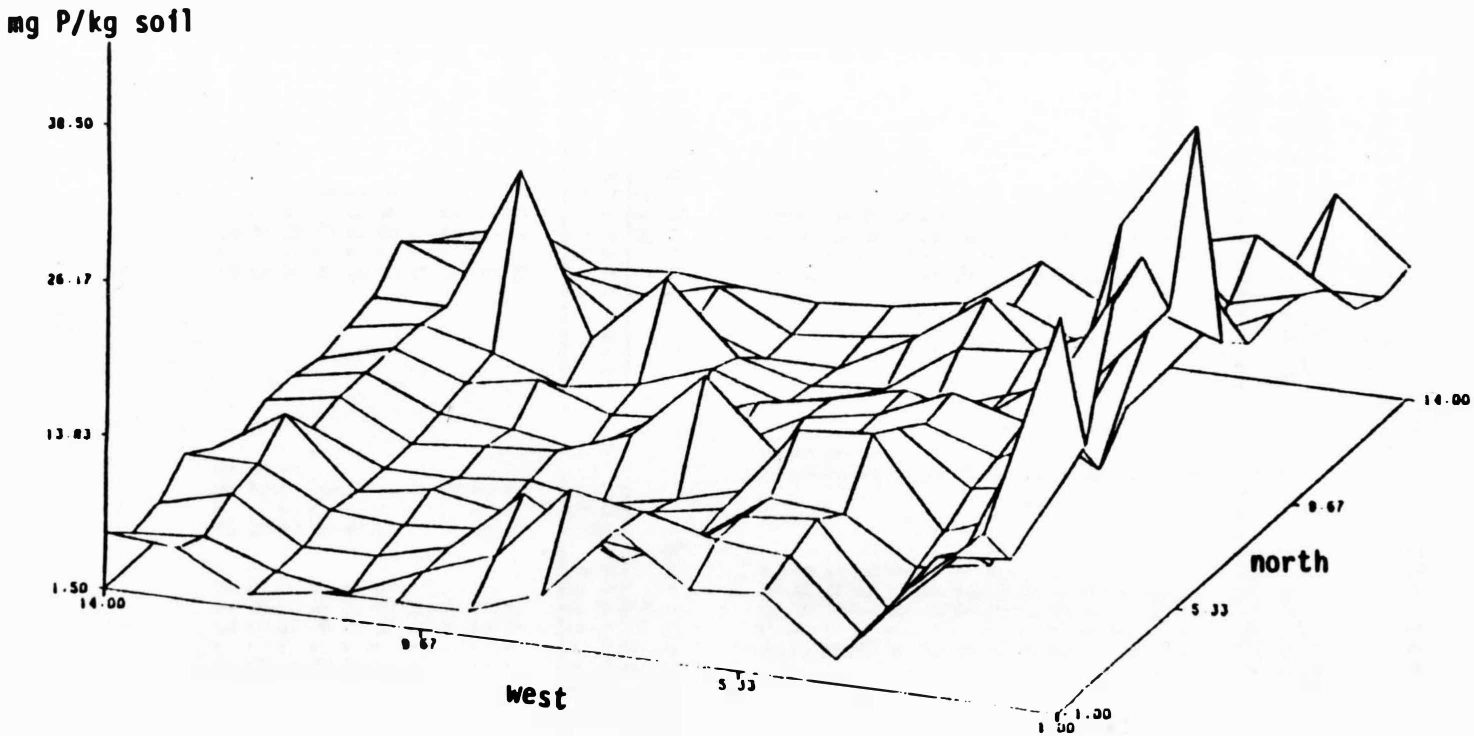


Figure B-11. Three dimensional representation of the original soil phosphorus test values of site 6.



Transformed Values

Figure B-12. Three dimensional representation of the transformed soil phosphorus test values of site 6.



Original Values

Figure B-13. Three dimensional representation of the original soil phosphorus test values of site 7.

Table B-1. Semivariance values of the four directional semivariograms of site 1.

North-South Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	47.7
2	30.5	67.1
3	45.7	87.2
4	61.0	97.9
5	76.2	105.7
6	91.4	110.9
7	106.7	91.6
8	121.9	63.8
9	137.2	56.8
10	152.4	50.0
11	167.6	45.8
12	182.9	39.3
13	198.1	48.3
14	213.4	44.4

East-West Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	52.7
2	30.5	87.6
3	45.7	102.1
4	61.0	103.7
5	76.2	111.1
6	91.4	110.3
7	106.7	99.2
8	121.9	75.7
9	137.2	62.1
10	152.4	59.6
11	167.6	61.0
12	182.9	45.5
13	198.1	60.9
14	213.4	110.3

Northwest-Southeast Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	57.9
2.8	42.7	92.8
4.2	64.0	132.6
5.6	85.3	135.6
7.0	106.7	148.3
8.4	128.0	132.5
9.8	149.4	100.4
11.2	170.7	40.8
12.6	192.0	64.5
14.0	213.4	53.0

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	69.6
2.8	42.7	108.0
4.2	64.0	121.1
5.6	85.3	127.0
7.0	106.7	131.8
8.4	128.0	139.3
9.8	149.4	111.6
11.2	170.7	59.0
12.6	192.0	52.9
14.0	213.4	58.2

Table B-2. Semivariance values of the four directional semivariograms of site 2.

North-South Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	27.2
2	30.5	34.8
3	45.7	39.5
4	61.0	42.0
5	76.2	39.6
6	91.4	40.8
7	106.7	36.7
8	121.9	42.7
9	137.2	47.1
10	152.4	52.0
11	167.6	49.0
12	182.9	36.1
13	198.1	41.7
14	213.4	23.3

East-West Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	37.7
2	30.5	51.2
3	45.7	53.0
4	61.0	51.9
5	76.2	58.5
6	91.4	49.9
7	106.7	43.6
8	121.9	42.2
9	137.2	36.3
10	152.4	25.3
11	167.6	31.6
12	182.9	27.9
13	198.1	25.7
14	213.4	20.0

Northwest-Southeast Semivariogram

lag (h)	distance meters	semivariance ($\gamma(h)$)
1.4	21.3	38.9
2.8	42.7	50.1
4.2	64.0	49.1
5.6	85.3	45.5
7.0	106.7	43.7
8.4	128.0	35.5
9.8	149.4	29.4
11.2	170.7	23.0
12.6	192.0	21.3
14.0	213.4	9.5

Northeast-Southwest Semivariogram

lag (h)	distance meters	semivariance ($\gamma(h)$)
1.4	21.3	39.5
2.8	42.7	47.3
4.2	64.0	49.3
5.6	85.3	50.3
7.0	106.7	40.3
8.4	128.0	49.0
9.8	149.4	54.2
11.2	170.7	64.5
12.6	192.0	70.7
14.0	213.4	49.0

Table B-3. Semivariance values of the four directional semivariograms of site 3.

North-South Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	9.4
2	30.5	12.4
3	45.7	11.0
4	61.0	11.4
5	76.2	14.6
6	91.4	14.2
7	106.7	11.3
8	121.9	10.9
9	137.2	13.8
10	152.4	13.0
11	167.6	13.1
12	182.9	16.1
13	198.1	15.2
14	213.4	20.2

East-West Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	6.6
2	30.5	9.2
3	45.7	9.6
4	61.0	11.2
5	76.2	10.5
6	91.4	9.5
7	106.7	9.9
8	121.9	9.0
9	137.2	8.0
10	152.4	9.1
11	167.6	10.8
12	182.9	12.2
13	198.1	10.6
14	213.4	14.3

Northwest-Southeast Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1.4	21.3	9.9
2.8	42.7	13.9
4.2	64.0	12.1
5.6	85.3	10.6
7.0	106.7	12.2
8.4	128.0	15.2
9.8	149.4	13.4
11.2	170.7	12.6
12.6	192.0	16.4
14.0	213.4	10.7

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1.4	21.3	8.4
2.8	42.7	10.7
4.2	64.0	8.4
5.6	85.3	8.3
7.0	106.7	10.2
8.4	128.0	12.0
9.8	149.4	10.5
11.2	170.7	9.0
12.6	192.0	9.0
14.0	213.4	9.8

Table B-4. Semivariance values of the four directional semivariograms of site 4.

North-South Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	58.3
2	30.5	72.0
3	45.7	91.3
4	61.0	100.6
5	76.2	104.4
6	91.4	110.6
7	106.7	91.0
8	121.9	100.6
9	137.2	91.6
10	152.4	95.1
11	167.6	119.9
12	182.9	156.2
13	198.1	215.1
14	213.4	242.5

East-West Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1	15.2	39.1
2	30.5	45.6
3	45.7	55.2
4	61.0	70.9
5	76.2	76.8
6	91.4	88.5
7	106.7	89.8
8	121.9	83.9
9	137.2	82.1
10	152.4	78.4
11	167.6	84.7
12	182.9	78.2
13	198.1	47.4
14	213.4	64.0

Northwest-Southeast Semivariogram

lag (h)	distance (meter)	semivariance ($\gamma(h)$)
1.4	21.3	68.8
2.8	42.7	87.6
4.2	64.0	91.5
5.6	85.3	83.7
7.0	106.7	70.5
8.4	128.0	66.6
9.8	149.4	74.6
11.2	170.7	99.1
12.6	192.0	73.4
14.0	213.4	63.4

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance ($\gamma(h)$)
1.4	21.3	56.9
2.8	42.7	66.6
4.2	64.0	87.1
5.6	85.3	94.5
7.0	106.7	102.7
8.4	128.0	131.1
9.8	149.4	119.4
11.2	170.7	135.5
12.6	192.0	83.6
14.0	213.4	99.9

Table B-5. Semivariance values of the four directional semivariograms of site 5.

North-South Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	25.7
2	30.5	30.7
3	45.7	35.1
4	61.0	36.2
5	76.2	35.0
6	91.4	38.3
7	106.7	28.8
8	121.9	33.1
9	137.2	30.7
10	152.4	33.3
11	167.6	31.8
12	182.9	35.0
13	198.1	29.7
14	213.4	29.8

East-West Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	43.3
2	30.5	48.4
3	45.7	36.8
4	61.0	43.6
5	76.2	40.8
6	91.4	44.9
7	106.7	48.2
8	121.9	45.8
9	137.2	56.3
10	152.4	54.5
11	167.6	46.9
12	182.9	63.4
13	198.1	58.2
14	213.4	37.1

Northwest-Southeast Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	43.0
2.8	42.7	52.7
4.2	64.0	43.9
5.6	85.3	41.4
7.0	106.7	39.4
8.4	128.0	53.6
9.8	149.4	54.1
11.2	170.7	48.9
12.6	192.0	55.9
14.0	213.4	58.6

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	47.2
2.8	42.7	45.5
4.2	64.0	36.1
5.6	85.3	40.2
7.0	106.7	41.4
8.4	128.0	40.3
9.8	149.4	44.9
11.2	170.7	48.3
12.6	192.0	50.6
14.0	213.4	31.0

Table B-6. Semivariance values of the four directional semivariograms of site 6.

North-South Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	70.2
2	30.5	86.5
3	45.7	99.3
4	61.0	118.5
5	76.2	150.2
6	91.4	184.1
7	106.7	215.6
8	121.9	261.1
9	137.2	291.8
10	152.4	340.6
11	167.6	379.0
12	182.9	347.7
13	198.1	412.2
14	213.4	338.5

East-West Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	15.2	61.6
2	30.5	75.7
3	45.7	83.4
4	61.0	78.0
5	76.2	108.8
6	91.4	141.7
7	106.7	161.6
8	121.9	179.6
9	137.2	187.2
10	152.4	231.8
11	167.6	239.8
12	182.9	245.9
13	198.1	331.6
14	213.4	440.7

Northwest-Southeast Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	83.9
2.8	42.7	107.8
4.2	64.0	124.3
5.6	85.3	158.9
7.0	106.7	243.1
8.4	128.0	322.5
9.8	149.4	417.5
11.2	170.7	546.9
12.6	192.0	677.8
14.0	213.4	797.0

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	21.3	70.4
2.8	42.7	76.2
4.2	64.0	90.5
5.6	85.3	78.5
7.0	106.7	81.1
8.4	128.0	71.0
9.8	149.4	70.8
11.2	170.7	80.4
12.6	192.0	112.5
14.0	213.4	199.3

Table B-7. Semivariance values of the four directional semivariograms of site 7.

North-South Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	18.3	48.0
2	36.6	89.3
3	54.9	108.8
4	73.2	109.9
5	91.4	142.3
6	109.7	175.2
7	128.0	205.3
8	146.3	242.2
9	164.6	293.5
10	182.9	353.7
11	201.2	419.9
12	219.5	524.2
13	237.7	700.5

East-West Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1	18.3	27.3
2	36.6	33.7
3	54.9	40.9
4	73.2	50.2
5	91.4	49.0
6	109.7	62.9
7	128.0	71.2
8	146.3	77.3
9	164.6	74.9
10	182.9	81.7
11	201.2	70.8
12	219.5	72.6
13	237.7	80.4

Northwest-Southeast Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	25.6	52.6
2.8	51.2	99.5
4.2	76.8	117.7
5.6	102.4	137.1
7.0	128.0	181.2
8.4	153.6	239.3
9.8	179.2	309.1
11.2	204.8	365.5
12.6	230.4	334.6

Northeast-Southwest Semivariogram

lag (h)	distance (meters)	semivariance (γ(h))
1.4	25.6	54.5
2.8	51.2	94.8
4.2	76.8	100.6
5.6	102.4	89.8
7.0	128.0	107.1
8.4	153.6	106.7
9.8	179.2	125.2
11.2	204.8	157.5
12.6	230.4	188.9